DEPARTMENT OF THE AIR FORCE
AIR FORCE CIVIL ENGINEER CENTER

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22 August 2016

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and

Mr. Wayne Miller, P.E., R.G.
Arizona Department of Environmental Quality
1110 West Washington Street, 4415B-1
Phoenix, Arizona 85007

Subject: Submission of "Response to ADEQ Comments dated 20 April 2016;
Response to EPA Comments dated 18 May 2016;
Response to EPA Memorandum (Dr. Eva Davis) dated 8 June 2016;
Response to EPA Comments Dated 17 June 2016 on the Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2
Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona"

The Air Force is pleased to submit the attached responses to Arizona Department of Environmental Quality (ADEQ) and U.S. Environmental Protection Agency (EPA) comments on the Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2 (Addendum #2). The responses provide requested information and clarifications regarding the Enhanced Bioremediation (EBR) phase of the remedial action at Site ST012, at the former Williams Air Force Base in Mesa, Arizona. Submittal of the final Addendum #2 will be dependent on resolution of informal dispute issues regarding characterization and containment which will be discussed in the August 24, 2016 Base Cleanup Team (BCT) meeting. Steam Enhanced Extraction system decommissioning and EBR construction remain on hold at Site ST012.

Please contact me at (315) 356-0810 or catherine.jerrard@us.af.mil if you have any questions regarding the responses to comments.

Sincerely,

CATHERINE JERRARD, PE
BRAC Environmental Coordinator

Attachments:

"Response to ADEQ Comments dated 20 April 2016; Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona."

"Response to EPA Comments dated 18 May 2016; Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona."

"Response to EPA Memorandum (Dr. Eva Davis) dated 8 June 2016; Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona."

"Response to EPA Comments Dated 17 June 2016 Remedial Design and Remedial Action Work Plan for Operable Unit 2 Draft Final Addendum #2. Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona."

cc: Addressee (1 and 1 CD)
ADEQ - Wayne Miller (2 and 1 CD)
AFCEC –Catherine Jerrard (1 and 1 CD)
CNTS – Geoff Watkin (1 and 1 CD)
TechLaw – Karla Brasaemle (1 and 1 CD)
USEPA – Eva Davis (1 and 1 CD)
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File

RESPONSE TO ADEQ COMMENTS DATED 20 APRIL 2016
DRAFT FINAL ADDENDUM #2
REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY, SITE ST012
FORMER WILLIAMS AFB, MESA, ARIZONA

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General Comments					
1				Please clarify throughout the document that the sulfate is being added to stimulate the subsequent microbial degradation of hydrocarbons. The response to EPA Specific Comment 42, as well as similar quotes found throughout the document text and appendices, erroneously suggests that sulfate ions alone will abiotically degrade hydrocarbons.	Text in Appendix C was the only specific location identified that implies abiotic degradation and was changed to: "The major assumptions made in screening the anaerobic approach considered that the anaerobic terminal electron acceptor (TEA) sulfate could be utilized by existing microorganisms and groundwater chemicals of concern (COCs) would be partitioned from the liquid to dissolved phase at significant enough rates that the added *TEA as sulfate would cause biodegradation of* the petroleum contamination." The response to U.S. Environmental Protection Agency (EPA) Specific Comment 42 on the draft version of Addendum 2 will also be corrected.
2				The term "sulfate degrading bacteria" and "sulfate degradation" are improper and should be corrected throughout the document to "sulfate-reducing bacteria" and "sulfate reduction."	Instances of degrading changed to reducing: Section 2.4: "The data collected for *decreases in sulfate concentration* from the enhanced bioremediation (EBR) Field Test indicated that the density of *sulfate-reducing* bacterial populations were higher and that dispersivity values and sulfate utilization rates were more favorable than assumed in remedial design and remedial action work plan (RD/RAWP) EBR modeling (Appendix C)."

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					Appendix C, Section 3.5: "The data collected for *decreases in sulfate concentration* from the EBR Field Test indicates that *sulfate-reducing* bacteria populations increased and that dispersivity values and sulfate utilization rates were more favorable than the assumed values used in the RD/RAWP EBR modeling."
3				Bio-traps are a copyrighted name, and as such, the "B" should be capitalized, and name is also hyphenated. Please correct this throughout the document.	Five instances of non-capitalized or non-hyphenated references to Bio-traps changed in Section 5.4. Five instances of non-capitalized or non-hyphenated references to Bio-traps changed in Appendix H.
4				The abbreviation qPCR is variously referred to as "quantifiable polymerase chain reaction", "qualitative polymerase chain reaction", and "quantified polymerase chain reaction". The correct term is "quantified polymerase chain reaction". Please correct this throughout the report.	Instance of "quantifiable" changed to "quantified" in Section 5.4. Instance of "qualitative" changed to "quantified" in notes of Table 5-1. Instance of "qualitative" changed to "quantified" in notes of Table 17-1 of Appendix H. Instance of "quantifiable" changed to "quantified" in Appendix H.
5				Please clarify how chloride concentrations are not expected to inhibit or slow EBR at this site. Chloride levels appear to be extremely high, and may inhibit some sulfate-reducing bacteria as well as others that are	It is recognized that chloride can, in general, inhibit cell growth. However, there are no literature or project examples that provide evidence to suggest high concentrations of chloride result in a reduction in effectiveness of sulfate-reducing bacteria. In fact, sulfate-

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				hoped to be used for target compound biodegradation during the EBR phase.	reducing bacteria are common in high salinity marine environments. Based on review of groundwater sample results collected prior to remedial action at ST012, the existing consortia of microorganisms have readily utilized naturally-available TEAs such that the flux of TEAs are rate-limiting in the respiration of the petroleum. The presence of high background chloride levels did not appear to inhibit biodegradation; instead, biodegradation is likely limited by the availability of TEAs. This discussion will be added to Section 3.1.2.
6				Please clarify why sulfate should be added to a system that currently has sulfate levels in tested wells as high as 310 mg/L.	Sulfate as high as 310 mg/L are only present upgradient or in areas that do not contain significant COC concentrations. The flux of sulfate by natural groundwater movement through contaminated areas is not sufficient to degrade the remaining mass in the projected timeframe. This discussion will be added to Section 3.1.2.
7				Please clarify how this site geochemistry suggests the presence of a robust indigenous sulfate-reducing population. If sulfate-reducing bacteria were a robust population at this site, sulfate concentrations would be expected to be highly depleted. However, concentrations are very high, suggesting a lack of sulfate utilization (and thus a lack of indigenous sulfate-reducing bacteria).	The site geochemistry data presented are for background wells that are not significantly contaminated by the COCs. Sulfate concentrations have been shown previously to be highly depleted in the source area indicating the presence of sulfate reducing bacteria (BEM, 1998). The flux of upgradient sulfate compared to other TEAs that are also depleted in the source area indicates that sulfate reducing bacteria provide a majority of the naturally occurring assimilative capacity for hydrocarbon degradation at ST012 (BEM, 1998).

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					This discussion will be added to Section 2.5.
8				ADEQ continues to request the installation of additional monitoring wells to characterize the full extent of NAPL east of the SEE treatment area, and dissolved-phase constituents exceeding the ROD remedial goals east, northeast, and north of the site. Specifically, additional wells should be installed north of well W36, northeast of well W34, and east of Sossaman Rd. between wells W24 and W38.	Upon completion of construction and installation of Phase 1 of EBR implementation, Phase 2 is planned, if necessary, to provide further characterization of the extent of light non-aqueous phase liquid (LNAPL) and dissolved phase concentrations. Locations indicated in the comment and other areas will be considered based on the characterization data collected during the Phase 1 drilling and baseline sampling. Air Force responses dated 19 May 2016 to the joint EPA/Arizona Department of Environmental Quality (ADEQ) letter dated 3 May 2016 provide approaches to addressing each of the identified areas of concern.
Specific Comments					
1	-	2.4	522-527	See the evaluation of the response to ADEQ General Comment 2. The referenced EBR Field Test, along with 18-year-old geochemical data, is not enough to conclusively determine that sulfate-reduction will be the dominant microbial process for EBR. Only after the site has cooled enough for proper geochemical and microbial sampling can this be accurately determined.	The Balanced Environmental Management Systems (BEM) report produced in 1998 provides a representative approximation of geochemical/biological site conditions not under the influence of steam-enhanced extraction (SEE) operations. Within that report there is evidence of significant sulfate-reducing bacterial activity at the site. During the EBR Field Test, sulfate reducing bacteria concentrations increased and the sulfate utilization rate was greater than expected. Because the majority of the targeted area for EBR is outside of the SEE treatment area, and geochemical effects on those areas from SEE treatment are expected to be minimal, the historical data combined with the EBR pilot test data is sufficient to support that sulfate reduction will be the dominant microbial process for EBR.

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					Performance evaluation monitoring will be used to confirm sulfate reduction as the dominant process during EBR by monitoring COC and sulfate concentrations in monitoring wells as described in the RD/RAWP. The RD/RAWP also includes microbial analysis to be performed post injection to identify the active and dominant microbial population at the site.
2	-	2.4	527-528	Please clarify the statement that, "sulfate amendment can either be used solely or in combination with aerobic methods to achieve remediation goals." The use of sulfate to stimulate the strongly anaerobic process of sulfate-reduction is not compatible with aerobic methods of bioremediation. Sulfate reduction occurs only under highly reduced environmental conditions, while aerobic respiration occurs only under highly oxidized environmental conditions. Thus, sulfate-reduction cannot be used in combination with aerobic methods.	The different TEAs could be implemented sequentially or in different areas. The sentence was revised as follows: "Sulfate amendment can either be used solely or in combination with aerobic methods *(either sequentially or in different areas)* to achieve remediation goals."
3	-	3.1.3	625	Please correct and clarify the statement, "natural site conditions are predominantly based on the activity of sulfate-reducing bacteria." Site biogeochemical conditions are not based on the activity of the indigenous bacteria. Rather, the members of the indigenous bacterial population and their activity is based on, and determined by, site biogeochemistry.	Changed text in Section 3.1.3 to: "…natural site conditions *reflect that sulfate-reducing bacteria are the predominant indigenous bacterial population*."
4	3-2	-	626-628	See the evaluation of the response to ADEQ General Comment 1. The statement assumes *a priori* knowledge that does not	The point of the bullet is that the sulfate reducing bacteria stimulated by the EBR will also have a long-term source of sulfate from upgradient

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				appear to exist regarding the indigenous microbial population. Furthermore, this statement assumes that sulfate-reducers dominate the indigenous population - something that has not been proven. ADEQ has specifically questioned and asked to have this investigated.	groundwater. With implementation of EBR, sulfate reducing bacteria will be the dominant established population. The dominant established population will be confirmed via microbial analysis between six and twelve months following the initiation of sulfate injections, as shown in Table 5-1. The bullet has been revised as follows to clarify: "influent upgradient background sulfate can supplement sulfate amendments to promote *petroleum hydrocarbon* degradation during and after EBR without having to change the *established* bacterial populations or redox conditions;"
5	3-5	-	728	What specific "rate-limiting geochemical conditions" will be monitored, and what is the plan for maintaining effective EBR if one of these adverse conditions is encountered?	Changed text in Section 3.2.3: "… or rate-limiting geochemical conditions *(e.g., pH, oxidation-reduction potential (ORP), nitrogen and micronutrient concentration)."* If EBR is shown to be affected by monitored rate-limiting geochemical conditions, additional amendments may be added to the subsurface using the on-site injection system. A discussion of this situation is included in Section 4.2.3: Micronutrient Dosing.
6	3-7	-	826-827	The statement " ... other compounds will degrade and consume sulfate in the process" is not accurate. Please revise this to "Indigenous microbes will consume sulfate while degrading compounds other than those targeted".	Text changed: "Although benzene, toluene, ethylbenzene, xylene, and naphthalene (BTEX+N) are the primary COCs, indigenous microbes will consume

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					sulfate while degrading non-targeted compounds."
7	-	4.2.2	-	Please detail how both population surge/crash and plugging of the formation with biomass will be prevented.	Biomass is expected to surge in the formation where sulfate concentrations are optimum and above twice half saturation. In these locations some level of formation plugging or reduction of pore space is inevitable, however; it is anticipated to have minimal negative consequences on the remediation of petroleum hydrocarbons. Conversely, the population surge will assist in retaining TEA in the vicinity of petroleum impacted media. Microbial populations are expected to follow typical growth phases with the introduction of abundant TEA. The immediate response is generally a lag phase (little or no population growth) during which the microorganisms adjust or evolve to the change in geochemical conditions. As the consortium diversity realigns, exponential growth is anticipated until zero-order or maximum utilization is reached. Since the petroleum substrate is expected to change in bioavailability over time, variability in the maximum utilization rate and consortium diversity is also anticipated to change. Ultimately, the system is expected to return to natural or background levels and diversity as the petroleum hydrocarbon source and sulfate are degraded and mineralized. The following text was added to Section 4.2.5:

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					"Biofouling. It is anticipated that the high ionic strength of the injection solution will reduce plugging of the formation with biomass by inhibiting microbial growth in the immediate vicinity of injection wells, thereby allowing use of these wells for future dosing. However, it is also anticipated that as sulfate concentrations drop at the injection well sites microbial blooms may occur along with biofouling of the well screen and filter pack. If the wells are affected by biofouling, one or more of the following two courses of action (or similar variations on these actions) will be implemented: *1. Injection wells will be pressurized to deliver TEA solutions into wells.* *2. Injection and/or extraction wells will be redeveloped by mechanical removal (e.g., hydrojet, surge, bail) and/or chemical addition (e.g., biocide) could be employed to restore well function."*
8	-	4.2.3	-	a) Please detail a correct micronutrient monitoring schedule, as well as all micronutrient components that must be monitored. Although some micronutrients are listed in this section, the most common one to deplete (even for sulfate-reducers) is bioavailable nitrogen. This nitrogen is critical, as it is the basis of DNA, RNA, all proteins, and many other biomolecules. Bioavailable nitrogen can quickly stall all bioattenuation if lacking,	a) Field analyses of ground water samples will include geochemical parameters (temperature, dissolved oxygen, pH, redox potential, and specific conductance) and total organic carbon. Laboratory analyses will include geochemical parameters not estimated in the field: chloride, sulfate, sulfide, nitrate, arsenic, manganese, total and dissolved iron, ortho- and total phosphorus, carbon dioxide (as free calcium carbonate), methane, total organic carbon, alkalinity (total, as calcium carbonate), bicarbonate (as calcium

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				and its concentrations must be monitored before any TEA addition as well as regularly during the EBR event. Failure to properly monitor micronutrient concentrations during the multi-year EBR event can result in early and undetected failure of EBR. b) Please describe the components of the suggested Bionetix MICRO 14 amendments. c) Please describe how decisions will be made regarding which possible micronutrient additions will be made, how decisions about the actual delivery method and concentration will be made, and what type of subsurface monitoring will be conducted to ensure a beneficial impact on COC bioattenuation.	carbonate), and carbonate (as calcium carbonate). These parameters will be sampled prior to TEA addition and intermittently during EBR to assess if the availability of any of these elements or compounds are potentially limiting respiration. Depending on the comparison of baseline results to results during EBR testing, additional amendments may be added to maintain robust degradation. b) Bionetix product MICRO 14 is a potential candidate for nutrient amendment if required. MICRO 14 is a proprietary blend of minerals, vitamins, and cellular building blocks that has been developed to support nutrient deficient groundwater at sites where enhanced bioremediation is underway. It provides a balanced nutrient blend for the microbial activity and boosts bacterial performance and rates of degradation of target substances. A product description sheet may be found here: http://www.bionetix-international.com/products/biostimulants.html c) Nutrient limitation will be assessed indirectly as diminished sulfate-reducing activity. Sulfate-reducing activity can be monitored through hydrocarbon concentrations (lack of contaminant reductions), sulfate concentrations (lack of sulfate utilization) and periodic qPCR (quantified polymerase chain reaction) monitoring. If evidence of nutrient limitation is observed, data will be evaluated to determine whether the cause

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					is limitation of macro or micro-nutrients. Macro nutrients (e.g. nitrogen and phosphorous) will be measured directly. If analysis results reveal a single rate-limiting macro-nutrient then that single nutrient will be blended into the TEA stock solution in proportion to the observed concentration reduction. If diminished sulfate-reducing activity is observed and the macro-nutrients are present, micro-nutrient limitation shall be assumed and Micro 14 shall be added to the TEA. The above information will be added to Section 4.2.3.
9	-	4.2.5	-	Please describe plans to monitor and prevent biofouling of the formation.	The following will be added to the end of Section 4.2.5: "Biofouling. It is anticipated that the high ionic strength of the injection solution will reduce plugging of the formation with biomass by inhibiting microbial growth in the immediate vicinity of injection wells, thereby allowing use of these wells for future dosing. However, it is also anticipated that as sulfate concentrations drop at the injection well sites microbial blooms may occur along with biofouling of the well screen and filter pack. If wells are biofouled, two courses of action will be considered: 1. Injection wells will be pressurized to deliver TEA solutions into wells. 2. Injection and/or extraction wells will be redeveloped by mechanical removal (e.g.,

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					hydrojet, surge, bail) and/or chemical addition (e.g., biocide) could be employed to restore well function."
10	-	5.1.1	-	Please develop and explain a plan to monitor the indigenous microbial population to determine if EBR will be successful. Please detail how EBR microbial data will be compared to pre-EBR microbial data.	Text added to Section 5.4: "….The deoxyribonucleic acid (DNA) extracts will be analyzed by qPCR methods to identify and quantify sulfate reducing bacteria *and total bacteria. Uncultured DNA and protein extracts from waterborne aquifer microbes captured on sterile filters will be the primary material analyzed to assess microbial response to the addition of sulfate. qPCR conducted on metagenomics extract will be used to detect and quantify (by gene count) the abundance of sulfate-reducing bacteria (SRBs) and total bacterial population (EBAC) will be the primary method used to track response. The qPCR will target the detection of 16S ribonucleic acid (RNA) sequences unique to 1) SRBs and 2) all bacteria. It is recognized that this method excludes archaea; however, bacteria will occupy the majority of activity in the subsurface and provide a surrogate measure for archaea. In addition, protein extract consisting of phospholipid fatty acids derived from cell walls will be analyzed to assess the microbial diversity.*" In addition to these primary proteomic and metagenomics sampling and analysis, stable isotope probing using in-well microcosms (e.g., Bio-traps®), as discussed in Section 5.4, will be utilized to verify the biodegradation of target COCs.

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					Table 5-1 provides a detailed description and schedule for the microbial monitoring proposed. Pre-EBR populations based on qPCR will be compared to populations during EBR to look for order of magnitude type changes in sulfate reducing bacteria. While increases in sulfate reducing bacteria populations may be beneficial, if initial populations are reasonable and COC concentrations are declining, increases may not be required to demonstrate effectiveness.
11	5-8	-	1326-1328	The plan states that "microbes will be analyzed to determine if indigenous sulfate reducers are mineralizing and incorporating the COCs into their biomass". This is a misleading statement regarding the capabilities of the SIP samplers and the data they will provide. Although the Bio-trap analysis will be able to confirm if indigenous microbes have degraded target compounds, this technology will not be able to confirm the identity of the organism (or the identity of the class of organism, such as sulfate-reducers) responsible for this biodegradation. Instead, the SIP samplers will only be able to confirm that some type of indigenous microbe may have degraded target COCs. Furthermore, by isolating DNA from the SIP samplers in order to run a qPCR on sulfate-reducing bacteria, the only data obtained from this action will be to quantify the sulfate-reducing population from within the SIP samplers. This will still not confirm that these	The statement “microbes will be analyzed to determine if indigenous sulfate reducers are mineralizing and incorporating the COCs into their biomass” has been changed to read: “…genetic material from the Bio-traps will be analyzed to assess the presence and quantity of SRBs and EBAC. The biomass will also be analyzed to assess if labeled carbon from the SIP is present; and at what concentration. These lines of evidence will provide improved confidence that SRBs are directly responsible for mineralization of target COCs.”

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				sulfate-reducing bacteria are, in fact, responsible for target-compound biodegradation. Furthermore, this qPCR will quantify the SRB population found within the SIP sampler - a sampler which is designed to be somewhat a mimic of the natural environment but not an exact replica. Thus, the qPCR data is arguably of a more qualitative nature and not truly a quantitative nature.	
12	-	6.1	-	It is stated that EBR will continue until conditions are such that monitored natural attenuation will be able to take over as the remediation pathway of choice. Please detail how this EBR endpoint will be determined, and please include what variables will be monitored as part of this determination.	The EBR endpoint will be determined based on an update to the groundwater model as stated in Section 6.1. The model will be updated based on actual data collected during EBR and include uncertainty evaluations. To clarify this approach the end of Section 6.1 has been updated as follows: "It is anticipated that the transition to monitoring will be supported by updates to the groundwater model using data from EBR for contaminant and sulfate concentrations to show projected conditions in the future consistent with the remedial action objectives (RAOs) and Cleanup Levels. The groundwater model will be updated based on data collected during active EBR and the evaluation will include sensitivity analysis of input parameters to evaluate uncertainty."

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Evaluation of Response to Comments				
1	Replication of ADEQ General Comment 1 (reference ADEQ FPU16-167, Feb.11, 2016): ADEQ recommends that additional microbial analyses be performed at various site locations to determine if non-sulfate-reducing bacteria play a significant role in the degradation of site constituents. It is currently unknown if sulfate-reducers are the dominant hydrocarbon-degrading species in the system.	The addition of SIP within each of the hydrostratigraphic zones has been added to the monitoring plan. An entry was added to Table 5-1 detailing sample type and frequency, and a narrative was added to Section 5.4 - Groundwater Monitoring Well Sampling, as discussed below in General Comment 3. This addition will provide evidence that COCs are being mineralized and incorporated into biomass. SIP analysis results, in combination with COC and TEA sampling and analysis, will provide sufficient data to assess enhanced sulfate reduction at the site. Primary assumptions in natural attenuation assessments and models presented previously for the site (BEM TEE Pilot Test Report, 2011 and Natural Attenuation Report, 1998) consider instantaneous TEA utilization over the volume impacted with petroleum contamination; and, across the primary TEAs, oxygen, nitrate, iron, sulfate, and carbon dioxide. The approach presented previously is widely accepted as a model for natural attenuation; however, it oversimplifies the spatial and temporal distribution of TEA utilization. For instance, aerobic and sulfate reduction do not occur in the same space simultaneously. Naturally available oxygen is depleted rapidly and aerobic biodegradation is predominant at the edges of the plume; anoxic nitrate utilization	ADEQ recommends that additional microbial analyses be performed at various site locations to determine if non-sulfate-reducing bacteria play a significant role in the degradation of site constituents. It is currently unknown if sulfate-reducers are the dominant hydrocarbon-degrading species in the system.	It has been interpreted based on TEA mass flux and depleted TEA concentrations co-located with higher COC concentrations that, historically, sulfate reducing bacteria are the dominant population that play a role in hydrocarbon degradation. The addition of sulfate is expected to further evolve the current consortia to be sulfate-reducing dominant. Since the presence and activity of SRBs is proven with a high level of certainty, the addition of abundant sulfate will stimulate and shift the diversity of the aquifer consortia to be SRB dominant. Additional microbial analysis (total eubacteria analysis by qPCR) was added to Table 5-1 and the following text was added to Section 5.4: "The Bio-traps will be retrieved from the well and the *genetic material from the Bio-traps will be analyzed to assess the presence and quantity of SRBs*

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		occurs within a volume that overlaps the inner boundary of predominant oxygen utilization and the outer boundary of metals reduction. So long as the concentration and mass of substrate and petroleum contamination is sufficient to not be rate limiting, methanogenesis will be predominant in some space at the core of the impact, considering flow rate and direction and naturally occurring TEA flux. Natural biodegradation at ST012 follows this process of TEA utilization; and, at some locations and over some volume within the petroleum impacted subsurface, sulfate reduction is the predominant biodegradation pathway for petroleum hydrocarbons. The natural flux of sulfate limits the biodegradation rate of the petroleum hydrocarbon contamination. Similar to enhanced aerobic biodegradation; it is assume that if the TEA sulfate and petroleum substrate are abundant and available at concentrations that do not limit biodegradation then the sulfate will be utilized to respire the petroleum. The addition of sulfate as proposed in the design will tip the scales in favor of sulfate reduction as the dominant reduction pathway for an area and mass of petroleum impacted subsurface that are much greater than under natural conditions.		*and total eubacteria (EBAC). The biomass will also be analyzed to assess if labeled carbon from the SIP is present; and, if it is, at what concentration. These lines of evidence will provide improved confidence that SRBs are directly responsible for mineralization of target COCs.*" And, "The DNA extracts will be analyzed by *quantified* polymerase chain reaction (qPCR) methods to identify and quantify sulfate-reducing bacteria *and EBAC. Uncultured DNA and protein extracts from waterborne aquifer microbes captured on sterile filters will be the primary material analyzed to assess microbial response to the addition of sulfate. qPCR conducted on metagenomics extract will be used to detect and quantify (by gene count) the abundance of SRBs and EBAC will be the primary method used to track response. The qPCR will target the*

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				detection of 16S RNA sequences unique to 1) SRBs and 2) EBAC. It is recognized that this method excludes archaea; however, bacteria will occupy the majority of activity in the subsurface and provide a surrogate measure for archaea. In addition, protein extract consisting of phospholipid fatty acids derived from cell walls will be analyzed to assess the microbial diversity.
2	Replication of ADEQ General Comment 2 (reference ADEQ FPU16-167, Feb. 11, 2016): Groundwater geochemistry results for the entire site should be reviewed to determine if a different terminal-electron acceptor dominates at other site locations. This will help discern if populations other than sulfate reducers are strongly active at the site and significantly impacting the polishing of site constituents.	Groundwater geochemistry for the entire site has been studied and reported previously (BEM, 1998). The geochemistry conditions presented in the BEM report generally show a consistent pattern throughout the source area with some variation in TEA concentration seen along the perimeters. The BEM report demonstrated that most of the electron donors are active at the site with depletion of oxygen, nitrate, and sulfate coinciding with elevated BTEX concentrations. The report also concluded that sulfate flux accounts for about 80% of the naturally occurring assimilative capacity for BTEX No changes made.	Geochemical data should be updated with current values and presented for analysis/evaluation. The referenced data is from a 1998 report, and is possibly no longer relevant due to the extreme impact that the steam treatments may have had on site geochemistry, which is critical to the success of the EBR stage.	Background geochemistry was investigated for areas outside of the contaminated areas as described in Section 2.5 and was generally found to be consistent with historical results for background. Geochemistry of contaminated wells outside the SEE thermal treatment zone (TTZ) were also characterized as part of the Field Test (see Appendix C). Additional geochemistry data will be collected inside and outside the SEE TTZs as part of the baseline sampling as described in Section 5.1. The data will be presented and evaluated as part of the

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				quarterly reports identified in Section 5.6.
3	Replication of ADEQ General Comment 3 (reference ADEQ FPU16-167, Feb. 11, 2016): The plan assumes that site microbial populations will rebound after steam treatment. This population rebound should be confirmed and monitored to ensure that this polishing step progresses as planned and that the degrading microbial population is (and remains) strong enough to achieve the remedial goal. ADEQ recommends stable isotope probe (SIP) analysis to specifically monitor the degrading population, providing information about population size, health, *insitu* target compound biodegradation rates, and possible	The application of SIP analysis is considered a viable line of evidence for confirmation that COCs are being biodegraded, mineralized and incorporated into biomass. The following text was added to section 5.4: "As a means to confirm if COCs are being incorporated into biomass and mineralized through bioremediation, Stable Isotope Probing (SIP) sampling and analysis will be conducted at six monitoring wells, two from each of the three hydrostratigraphic zones. One of the monitoring wells from each of the zones is located in the TTZ. These three wells are ST012-CZ2, ST012-UWBZ24, and ST012-LSZ10. The other three wells selected for SIP sampling and analysis are to evaluate LNAPL impact areas that are outside the TTZ. These three perimeter monitoring wells are ST012-CZ20, ST012-UWBZ31, and ST012-LSZ42. Bio-trap® samplers from Microbial Insights, seeded with synthesized forms of benzene, toluene, ethylbenzene, xylenes, and naphthalene containing carbon isotope J JC, will be placed in each well for approximately one month. The biotraps will be retrieved from the well and the microbes that grew on the bio-trap will be analyzed to determine if indigenous sulfate reducers are mineralizing and incorporating the COCs into their biomass. As	3a) Please detail how the proper length of time for sampler deployment will be determined and followed. The response states that the *Bio-trap*® SIP sampler will be deployed for approximately one month before being retrieved for analysis. However, this is a general timeframe provided by Microbial Insights to be used as a starting point in determining the proper length of deployment time. This time length should be adjusted based on site geochemical conditions and target compounds. If the assumed sulfate-reducing conditions are dominant, then experience with these samplers in anaerobic environments suggests that one month may not be enough time to properly allow for adequate target compound	3a) The timing for deployment of Bio-traps for stable isotope probing (SIP) following the addition of sulfate will be based on feedback from the groundwater sampling. Sulfate, COC concentrations, and general water quality sample results will be used to assess the timing and final location for deployment of the post-sulfate addition SIP. It is important that the SIP be deployed after the lag-phase and preferably after the exponential growth-phase has occurred. Depending on the feedback from the groundwater analyses SIP may be deployed at more than one time step. Additionally, the duration of the deployment will be adjusted based on feedback; however, the one-month, rule-of-thumb will likely prevail as a reasonable timeframe for attachment and generation of at least some biofilm. The substrate utilization rates at zero-order are anticipated to be

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	environmental stressors. It will also definitively prove in-situ target compound bioattenuation.	part of SIP analysis, two methods will be used to demonstrate biodegradation of the COC: • Quantification of I JC enriched phospholipid fatty acids (PLFA), which will indicate incorporation into microbial biomass; and, • Quantification of J JC enriched dissolved inorganic carbon (DIC), which indicates contaminant mineralization. In addition to the PLFA and DIC analyses conducted on the bio-trap sample; DNA will also be extracted from the samples. The DNA extracts will be analyzed by quantifiable polymerase chain reaction (qPCR) methods to identify and quantify sulfate reducing bacteria. The deployment of the bio-trap samplers for SIP sampling cannot be conducted in groundwater above 140 degrees Fahrenheit. Additionally, the biotraps should not be deployed until sulfate concentrations have reached the test well locations at concentrations significant enough to support zero-order sulfate reduction. Therefore, the timing of the SIP sampling will be determined in the field and based on feedback from field screening and sulfate/CDC groundwater analyses and alternate locations may be selected. Depending on the location of the planned SIP sampling, the duration for cooling, and the travel times for the sulfate SIP sampling and analysis is likely to occur	mineralization or conversion to biomass. 3b) Furthermore, referring to the Feb. 11, 2016 Comment 2, the current geochemistry is unclear. To assess the correct time interval that the samplers should be deployed requires an understanding of the current geochemistry. 3c) The response to Comment 3 also states that" ... DNA extracts will be analyzed by ... qPCR ... to identify and quantify sulfate-reducing bacteria." As stated in Comment 2, this will not address the ADEQ request to determine if non-sulfate-reducing bacteria play a significant role in the degradation of site constituents. Please detail how the ADEQ request will be addressed.	significantly higher than ambient biodegradation. At these higher rates reattachment and growth on the Bio-trap media is anticipated to be faster post-sulfate addition. 3b) As described in part 3a, water quality data will be evaluated from the baseline and post sulfate injection steps of EBR implementation. SIP analysis is proposed for six to twelve months after injections so this data will be available to assess geochemistry conditions at that time to make adjustments to the SIP deployment timeframe if necessary. 3c) In addition to qPCR analysis to detect and quantify SRBs from DNA, total bacteria (EBAC) analysis will be performed on the extract produced from the Bio-trap. Data on the detection and quantification of non-sulfate reducing genera within the bacterial community under

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		between 6 and 12 months following the start of the EBR sulfate additions and pumping. "		enhanced sulfate reduction conditions does not have significant value; however, if during the course of EBR treatment other bacterial genera require tracking; the DNA extract is cataloged with the laboratory allowing for additional qPCR analyses. EBAC has been added to Table 5-1, Section 5.4, and the QAPP. Additional details from this discussion will be added to Section 5.4.
4	ADEQ Evaluation of Air Force March 15, 2016 Responses (The following evaluation refers to responses related to ADEQ General Comment 6, and Specific Comments 3 and 4 [reference ADEQ FPU16-167, Feb. 11, 2016]. In general, the cited comments refer to data that suggests a significant fraction of the initial LNAPL	Excerpts of Air Force Response to Comment (reference Mar. 15, 2015): (Excerpted AF response to General Comment 6). "There is ample contact between LNAPL and groundwater to affect dissolved phase BTEX+N concentrations. Therefore, the concentrations of BTEX+N in extracted water do not provide reliable indication of whether the LNAPL sources are within or outside the TTZ." (Excerpted AF response to Specific Comment 3). "More recent data [NAPL composition] is available but does not show a significant change in composition." (Excerpted AF response to Specific Comment 4). "Extracted groundwater is mixed with extracted LNAPL in the extraction piping and	Simple mass balances demonstrate that these assertions are not valid. Throughout February and March 2016, the mass extraction rate of VOCs in the thermal accelerator (vapor recovery) averaged 1,880 pounds per day and was almost double the average mass extraction rate of LNAPL (1,044 lbs./day). This mass extraction rate did not exhibit a significant decay. In addition, recent	The original comments (General Comment 6 and Specific Comments 3 and 4 on the Draft) pertained to depletion of benzene content in the LNAPL from within the TTZs as it related to dissolved phase BTEX+N. Mass recovery in the vapor phase was not part of the original comments. The assertion that the "only possible source of this excess mass is residual LNAPL residing within soils heated to

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	remains in the TTZ after SEE shutdown, and is not accounted for in the EBR calculations.)	initial treatment system steps. Therefore, BTEX+N concentrations at the air stripper influent do not effectively differentiate between mass originating inside or outside the TTZ." (Excerpted and paraphrased AF response to Specific Comment 4). "The 90% reduction [in BTEX+N concentrations in residual LNAPL post-SEE] is based on experience from other sites. "	measures of LNAPL composition did not show a significant change. Hence, it is impossible for contact between LNAPL and extracted water to be the source of the excess vapor recovery rate. Also, the thermal zone was shrinking during this period, not expanding, such that LNAPL on the perimeter was cooling. Further, the vapor recovery rate of individual compounds exceeds the ambient solubility limit by roughly a factor of 10 based on the water extraction rate. The only possible source of this excess mass is residual LNAPL residing within soils heated to steam temperature. This residual LNAPL mass is almost certainly higher than the assumed mass of LNAPL in the post-SEE TTZ and used in the EBR calculations. Also, the assumed 90% reduction in	steam temperature" is incorrect. The mass extraction rate provided in the ADEQ evaluation for vapor recovery is determined using the composite influent stream into the thermal accelerator. As described in excerpt 4, mass recovery in the vapor phase is a combination of extracted vapors from the subsurface and transfers from LNAPL and dissolved phases in the piping and treatment system. Hence, the combination of influent streams, including the extended contact between LNAPL and extracted water in the transfer from extraction well to treatment system affects extracted water concentrations such that they are not reliable for evaluating LNAPL composition from within the TTZs. The responses did not contend that contact between LNAPL and extracted water was the primary source of excess vapors as implied by the evaluation of the response.

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			BTEX+N content is based on experience from other sites; however, no references, citations, or even site names were provided. Experience from this site does not suggest such a reduction.	The 90% reduction in BTEX+N was provided by TerraTherm based on their experience at other sites, but they could not identify sites were this data was specifically published for reference. LNAPL observations in SEE wells during the transition period between SEE and EBR along with baseline sampling and sampling during the initial phase of EBR will provide better insight into actual conditions within the SEE TTZs. In accordance with the phased EBR implementation plan and based on post-SEE site characterization and monitoring of initial EBR implementation, adjustments can be made in subsequent rounds of EBR injections.
5	ADEQ Evaluation of Air Force March 15, 2016 Responses: The following evaluation refers to responses related to ADEQ General Comments 4 and 7, and Specific	(Excerpted AF response to General Comment 4). "The model used in this addendum is an update to the 3D groundwater model that was included in the RD/RA WP. The 3D groundwater model was not used to simulate biodegradation or reduction of the sulfate. " (Excerpted AF response to General Comment 4). "The required mass of sulfate per injection	In general, the site remediation timeframe and Remedial Action Objective (RAO) attainments are not supported by calculations or estimates.	The site remediation timeframe and RAOs are supported by modeling in the RD/RAWP Appendix E. As described in the response to comments on the draft Addendum 2, the model provided in the RD/RAWP

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	Comment 13 [reference ADEQ FPU16-167, Feb. 11, 2016] In general, the site remediation timeframe and Remedial Action Objective (RAO) attainments are not supported by calculations or estimates.	well was assessed considering the distribution of contamination and the sulfate-reduction stoichiometry (Appendix A and Appendix F). Based on the sulfate reduction rate-kinetics analysis results (Appendix C) and considering the dispersion simulation results, maintaining a sulfate concentration above 8,000 mg/L (double the half saturation concentration) will reduce the mass of injected sulfate at a rate of 33 to 75 mg/L per day." (Excerpted AF response to General Comment 7). "Utilizing the model [provided in the RD/RA WP] now to predict the sulfate TEA utilization, LNAPL depletion, and COC decay is possible; however, this step has limited utility. " (Excerpted AF response to Specific Comment 13). "3D groundwater model was not used to assess the required mass or dosing of sulfate TEA"	As stated in the Work Plan, the groundwater modeling does not simulate sulfate biodegradation or reduction. The cited sulfate utilization rates appear to be based on current conditions of TEA limited reactions. Whereas during EBR reactions, with an excess of sulfate present, sulfate reactions will be governed by the availability of dissolved contaminants (NAPL dissolution). Flooding the subsurface with sulfate runs the risk of ambient flow sweeping it downgradient if LNAPL dissolution is slow. The utility of modeling the kinetics of dissolution and degradation upfront is to assess if meeting the RAOs in the desired timeframe is even possible under the assumed conditions. Site-specific LNAPL dissolution rates are available from the TEE	considers the presence and dissolution of residual LNAPL and LNAPL source zone depletion and simulates sulfate biodegradation. The MODFLOW-SURFACT model code used in the RD/RAWP modeling uses a local-equilibrium condition at each time step to estimate LNAPL dissolution. This differs from the rate-limited model described in the reference cited in the comment. As a part of the transition from active EBR to MNA, this multiphase flow and reactive transport model will be adjusted considering updated understanding of the kinetics and the distribution of residual LNAPL and remaining COCs. The site-specific LNAPL dissolution rates in the cited reference varied by more than an order of magnitude between two wells in relatively close proximity. The following is provided consistent with the response to

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			Pilot Test Evaluation Report and the following reference: Mobile, M., et al., *In-Situ Determination of Field-Scale NAPL Mass Transfer Coefficients: Performance, Simulation and Analysis.* Journal of Contaminant Hydrology, 2016. **187**: p. 31-46	EPA general comment 1 (18 May 2016): Concurrent with the implementation of EBR, monitoring and operational data will be evaluated on a regular basis to determine if the EBR+MNA approach will meet objectives and whether additional EBR or contingency actions are needed. Statistical and modeling evaluations of EBR progress will be conducted during the one to three year period after initial EBR injections commence. Inputs and assumptions used for the natural attenuation model included in RD/RAWP Appendix E will be updated to enhance predictions of achieving the estimated remedial timeframe. This will allow for remedy effectiveness to be evaluated based on comparison of operational data to the initial baseline and EBR data.

RESPONSE TO EPA COMMENTS DATED 18 MAY 2016
DRAFT FINAL ADDENDUM #2
REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY, SITE ST012
FORMER WILLIAMS AFB, MESA, ARIZONA

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General Comment					
1				The goal of the proposed remedial approaches (EBR+MNA after SEE) is to bring COPC groundwater concentrations down to meet required levels, within a fixed timeframe as required by RODA 2. Amec Foster Wheeler has conducted Site characterization and monitoring activities, various tests (including the EBR Pilot Test), and modeling exercises to develop assessments of the potential for EBR+MNA (after cessation of SEE) to effectively meet the required COPC groundwater concentrations in the required timeframe. As discussed in earlier reviews, conference calls, and meetings (and below in this present review), SEE, EBR (sulfate reduction based bioremediation) and MNA do have some potential for being useful for reducing COPC groundwater concentrations at the Site. However, there are numerous potential difficulties that may adversely affect implementation of the EBR and MNA remedial approaches, including, for example, problems with items such as:	Steam enhanced extraction (SEE) and enhanced bioremediation (EBR) is the remedy selected by the Air Force (AF) and U.S. Environmental Protection Agency (EPA), with concurrence from Arizona Department of Environmental Quality (ADEQ). The AF is committed to remedy implementation to achieve the remedial objectives within the estimated remedial timeframe as indicated by the Record of Decision Amendment 2 (RODA 2) remedy and in prior AF correspondence dated 29 March 2016 and 19 May 2016 addressing EPA comments. As specified in the comment, many actions have been implemented by the AF and its contractor towards effectively meeting the cleanup levels within the estimated remedial timeframe. However, the RODA 2 does not establish a “fixed” or “required” timeframe. Remedy design and implementation is being executed in accordance with achieving remedial objectives within the estimated remedial timeframe of 20 years. All of the potential difficulties listed in this comment were considerations known to the AF and EPA at the time of remedy selection and continue to be evaluated during remedial design/remedial action implementation. The AF agrees with EPA’s recommendation included in

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				• remaining source materials (i.e., LNAPL) that are not amendable to EBR or MNA, • COPCs (likely including LNAPL, in addition to dissolved COPCs) outside the area contemplated for treatment, • difficulty in effective distribution of reagents, • COPCs remaining in low-permeability zones that are little affected by EBR or MNA, • well fouling issues, • generation of high levels of sulfide (potentially affecting needed microbial activities, possibly causing vapor intrusion issues, and perhaps reducing aquifer permeability in some locations due to iron sulfide precipitation), and • variable rates of COPC degradation (i.e., rates that vary in different parts of the Site, and overall rates that vary significantly lower than those rates used in modeling EBR+MNA effectiveness and timeframes). Some of these issues can probably be dealt with by particular operational approaches (e.g., a rigorous schedule of well rehabilitation to alleviate well fouling issues, added injection and extraction wells to enhance distribution of reagents, etc.).	the comment: "it is recommended that within at the most two or three years after implementation of EBR, monitoring and operational data be carefully evaluated to determine if the data (primarily the COPC attenuation data; secondary data such as sulfate utilization are of much less importance for assessment of remedy effectiveness) show that the EBR+monitored natural attenuation (MNA) approach appears likely to be able to meet site goals within the remaining portion of the fixed remedial timeframe." The following text will be added to Section 4.2.5: "Concurrent with the implementation of EBR, monitoring and operational data will be evaluated on a regular basis to determine if the EBR and MNA approach will meet objectives and whether additional EBR or contingency actions are needed. Statistical and modeling evaluations of EBR progress will be conducted during the one-to-three-year period after initial EBR injections commence. Inputs and assumptions used for the natural attenuation model included in RD/RAWP Appendix E will be updated to enhance predictions of achieving the estimated remedial timeframe. This will allow for remedy effectiveness to be evaluated based on comparison of operational data to the initial baseline and EBR data. Contingency actions or

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				However, some of the issues (in particular, remaining source materials, COPCs in low-permeability zones or outside the area contemplated for treatment, and lower than anticipated rates of COPC degradation) may be difficult or impossible to effectively deal with without significantly changing the scope of the remedy. Such changes might include, for example, remobilizing SEE to deal with remaining LNAPL source materials or source materials in low permeability zones; extending EBR outside of the currently-proposed treatment area; or even by changing the proposed remedy altogether (e.g., choosing another remedial approach that is more effective/faster than EBR+MNA). In any case, it appears that there is good reason to be uncertain that EBR+MNA will be able to achieve remedial goals within the fixed timeframe, even within the TTZ. Therefore it is recommended that within at the most two or three years after implementation of EBR, monitoring and operational data be carefully evaluated to determine if the data (primarily the COPC attenuation data; secondary data such as sulfate utilization are of much less importance for assessment of remedy effectiveness) show that the EBR+MNA approach appears likely to be able to meet Site goals within the remaining portion of the fixed remedial timeframe. If not, final design	contingency remedies will be implemented as appropriate. Well rehabilitation, addition of injection or extraction wells, and other operational approaches listed in the comment are already included in the existing plan. Screening/evaluation of contingency actions based on actual remedy performance would be detailed in annual reports or technical memoranda." The estimated remaining mass after SEE is consistent with the RD/RAWP and implementation of EBR remains consistent with the remedy. Changes to the remedy are not currently warranted pending collection of additional information from phased site characterization and EBR implementation.

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				and implementation of the contingency remedies should begin immediately (it is assumed that potential contingency remedies would have already been screened and evaluated during the two or three years of EBR implementation).	
EBR Field Test Comments					
1	-	-	-	Note that while estimates of electron acceptor utilization (i.e., sulfate utilization, in this case) are useful, in that they provide an index of the importance of that electron acceptor in biogeochemical processes at the Site, and rates/total mass of electron acceptor used (which are useful design elements), such utilization estimates are not clearly and directly related to efficacy of using that electron acceptor to remediate the COPC. That is, because there are many electron donors present other than the COPCs BTEX+N (the COPCs represent about 10% of the JP-4 and AVGAS contaminants), a given mass of sulfate utilized does not mean that a corresponding stoichiometric amount of COPC was degraded. The actual degradation (or, at least, attenuation/disappearance) of COPCs is the overriding factor of importance, not sulfate utilization.	The objective of the push-pull test was to estimate the sulfate utilization and validate the assumptions in the RD/RAWP modeling regarding kinetics of the sulfate reducing bacteria. Although the data cannot define a direct connection between sulfate utilization rates and contaminant of concern (COC)/contaminant of potential concern (COPC) removal rates, the report does relate sulfate utilization to total petroleum hydrocarbon degradation in Section 3.4.
2	-	-	327-330	"*Initial results from Test America for the pull-phase of ST012-W11 were used to calculate the total amount of sulfate that was extracted from the groundwater. The results of this*	The field test work plan approach to use data from the extraction period was considered acceptable and reasonable prior to implementation of the field test. However, the proximity of ST012-W11 to upgradient

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				calculation indicated that more sulfate was extracted from the groundwater than was introduced during the push-phase of the field test." Therefore the approach of comparing total sulfate injected to total sulfate extracted was not usable for estimating sulfate utilization. Instead, groundwater samples taken during the shut-in phase were used for sulfate utilization estimation. Note, however, that only part of the sulfate concentration data taken during shut-in were deemed useful for estimating sulfate utilization because the normalized sulfate concentrations of the samples were higher than the normalized bromide tracer concentrations for most of the test period. Note also that the calculated (i.e., calculated according to how much sulfate or bromide was added to the injection solution) values for sulfate and bromide were significantly different from the measured values (i.e., lab-measured on samples taken from the injection solution) of sulfate and bromide in the injection solution. It is not clear why the lab-measured sulfate and bromide concentrations in groundwater samples were normalized using the calculated values in the injection solution, not the lab-measured values. In some cases, this approach made a significant difference in the normalized	background groundwater where sulfate was not depleted limited the use of data during extraction. More importantly, useful data on sulfate utilization was obtained during the shut-in period of the field test. The lack of useful data from the extraction period is not problematic because the shut-in period more closely represents the planned EBR approach. The primary objective of groundwater extraction during EBR is to provide sufficient groundwater movement to enhance distribution of the sulfate. Following field test data review, it was determined that the more conservative of the two values (calculated) would be used in assessing the respiration. Reassessing the kinetics with laboratory derived values instead of the calculated values would yield higher V_{max} and K_m estimates and result in higher predicted biodegradation rates. The approach to address the data limitation for the extraction period results was to use the more conservative (calculated) values. This information will be included in Section 3.4 of the Field Test Report.

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				values. It would be useful to explain why this approach was taken. Also, it would be useful to explain why the calculated values were in some cases so different from the lab-measured values, and how this difference might affect evaluation and interpretation of the results of the EBR Pilot Test, and reliability of lab-measured values.	
3	-	-	372-378	"*Due to the slow extraction rates achievable from ST012-W30, only 1,000 gallons of water was removed during the extraction phase compared to the 10,000 gallons targeted in the EBR Field Test Plan. This may be due to fouling of the well over time. Well fouling limits evaluation of hydraulic conductivity for the well. Extraction of a smaller volume of water than planned results in only partial extraction of the injected fluids. This limits evaluation of degradation kinetics; however, data from the shut-in phase is available for calculation of kinetic parameters.*" Here again the approach of comparing sulfate injected to sulfate extracted was not usable for calculating sulfate utilization, so samples of groundwater taken during shut-in were used. Note also that well fouling was a problem; it is very likely that well fouling will be a significant problem during full-scale	See response to comment number 2 on use of shut-in data. Comment acknowledged on well fouling. The discussion provided below is in response to ADEQ specific comment 9, "Please describe plans to monitor and prevent biofouling of the formation" This information will be added in Section 4.2.2. "Biofouling. It is anticipated that the high ionic strength of the injection solution will reduce plugging of the formation with biomass by inhibiting microbial growth in the immediate vicinity of injection wells, thereby allowing use of these wells for future dosing. However, it is also anticipated that as sulfate concentrations drop at the injection well sites microbial blooms may occur along with biofouling of the well screen and filter pack. If wells are biofouled, two courses of action will be considered: 1. Injection wells will be pressurized to deliver TEA solutions into wells.

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				implementation of EBR (i.e., during the injection of tons of sulfate, and extraction of groundwater for control of circulation of the sulfate and control of plume behavior).	2. Injection and/or extraction wells will be redeveloped by mechanical removal (e.g., hydrojet, surge, bail) and/or chemical addition (e.g., biocide) could be employed to restore well function."
4	-	-	383-392	*"Analytical concentration data for ST012-W11 presented in Table 2-1 show no significant change between the baseline and the post-shut-in period for most of the analytes evaluated. However, there is a decrease in total TPH and total VOC concentrations observed between these monitoring periods and the post- extraction sampling round. Additionally, sulfate, calcium and chloride concentrations for the post-shut-in period increased as well. These conditions were not expected and are interpreted to be a result of cleaner/background groundwater within part of the screened interval being drawn into the well rather than pulling only injected water back into the well. Historical groundwater monitoring upgradient of site contamination has shown background sulfate concentrations generally range from 250 to 300 mg/l (BEM, 1998) which is similar to the concentrations observed in ST012-W11 during the pull phase."*	See response to comment 2. Useful data on sulfate utilization was obtained during the shut-in period of the field test. The lack of useful data from the extraction period is not problematic because the shut-in period more closely represents the planned EBR approach. As documented in the Enhanced Bioremediation Field Test Plan, changes in sulfate concentration compared to conservative tracer (bromide) were the primary data to be used to estimate biodegradation kinetics. Changes in contaminant concentrations were not intended to be used to estimate biodegradation kinetics.

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				Therefore the interpretation of sulfate utilization and changes in contaminants in the EBR Pilot Test are problematic at best.	
5	-	-	394-396	"*Results for ST012-W30 presented in Table 2-2 indicate an increase in concentration for total TPH and total VOCs in both the post-shut-in sample and post-extraction sample in comparison with the baseline sample results.*" So it is not clear what useful effect, if any, sulfate injection might have on contaminant concentrations.	Demonstration of an effect on contaminant concentrations was not an objective of the EBR Field Test. The field test was a short-term test to evaluate sulfate kinetics. It is not unexpected for contaminant concentrations to increase during initial phases of short term testing for several reasons, such as temporary increases in contaminant solubility and/or transport into the groundwater phase and insufficient time for robust biodegradation to affect soil and groundwater concentrations. Site historical data clearly indicates that sulfate depletion is significant in locations of the site that have significant hydrocarbon concentrations. It is a reasonable extension to expect that additional sulfate injections will enhance the biodegradation process.
6	-	-	427-431	"*Water elevations from transducer data collected throughout the field test were evaluated for estimation of hydraulic parameters. However, groundwater elevation data from the transducers generally showed rapid and abrupt changes during the pull phases which was likely related to fouling of the well screens; this limited analysis of pull phase data for estimation of hydraulic conductivity.*"	Well fouling is recognized as likely to occur during EBR and operational procedures addressing well fouling are included in Addendum 2. Although it is unfortunate that the EBR field test did not provide reliable hydraulic conductivity data, the model is based on extensive historical hydraulic conductivity data. The model's hydraulic conductivity was originally refined based on calibration to field data (see Appendix M of the Thermal Enhanced Extraction Pilot Test Report). Prior to using the model for Addendum 2 preparation, model output using these hydraulic conductivity fields and the containment study

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				Again, fouling is likely to be a significant problem at full-scale. Also, the EBR Pilot Test was not able to provide useful estimates of hydraulic conductivity, as might have been expected. Hydraulic conductivity is an important parameter for designing models of groundwater flow, and reagent/contaminant fate and transport. The proposed remedial scheme for the Site depends largely on models for justifying the remedial approaches to be taken, and calculating remedial timeframes.	pumping rates was compared to the drawdowns observed during the containment study and provided a reasonable fit. Appendix E will be updated to include a graphic comparing the model and the measured drawdowns.
7	-	-	484-487	"*The normalized sulfate concentration is higher than the normalized bromide concentration for the majority of the shut-in period* [in well ST012-W11]*; however, after the initial 24 July 2014 sample, sulfate decreased faster than bromide and the data after this date are useful for evaluating the sulfate utilization rate.*" The data chosen for evaluating the sulfate utilization rate for well ST012-W11 were from only about 20 days at the end of the test period (the test period of about 48 days was from sulfate injection on July 21, 2014 to the end of extraction on September 7, 2014). So only a small part of the test period contributed data to the sulfate utilization analysis.	Comment acknowledged. As indicated, the data was useful for evaluating the sulfate utilization rate.
8	-	-	-	Given, then, the secondary importance of measures of sulfate utilization (i.e., not a	Timeframes for remediation by EBR and MNA were evaluated in the RD/RAWP prior to the

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				direct measure of COPC degradation), the various problems mentioned above in respect to measuring the sulfate utilization, and problems with well fouling and hydraulic measurements, and the relatively small amount of usable data generated), it is difficult to derive strong and useful conclusions from the results of the EBR Pilot Test. Also, the EBR Pilot Test involved only a very small portion of a large and complex site, over a short time period (i.e., as opposed to a twenty-year remedial timeframe) so extrapolation of the EBR Pilot Test results to the rest of the Site, over a long timeframe, increases uncertainty. In sum, the EBR Pilot Test appears to provide data of limited utility for design on a full-scale EBR effort, and particularly for evaluating and predicting remediation effectiveness in achieving the desired COPC concentrations, degradation rates, and remedial timeframes. It is concluded, therefore, that the results of the EBR Pilot Test should be used with caution when assessing the potential for EBR remediation at the Site. Modeling efforts based on parameters derived from the EBR Pilot Test should be considered to be highly uncertain as far as predicting contaminant attenuation rates (both for EBR and MNA), and for predicting remedial timeframes. Given the limited utility of the EBR Pilot Test data, and the fact that the efficacy and	availability of data from the EBR Field Test. EBR and MNA timeframes were not estimated in RD/RAWP Addendum 2 so the EBR Field Test data has not been used yet in timeframe modeling. Although the EBR Field Test was of short duration, it did not indicate input parameters for the RD/RAWP modeling (RD/RAWP Appendix E) to be incorrect and did indicate some parameters used in the RD/RAWP modeling may be conservative. The collection of long-term site-wide site-specific monitoring data to evaluate effectiveness and rates of sulfate reduction-based biodegradation of the COPCs referenced in the comment is consistent with the RD/RAWP Addendum 2 approach and is included during phased EBR implementation, evaluation and optimization. Updates to the RD/RAWP Appendix E model are planned based on initial implementation as recommended by EPA in general comment 1, above.

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				timeframes of both the EBR full-scale effort and the proposed MNA following are based on modeling using the EBR Pilot Test data and literature (i.e., non-site-specific) data, (i.e., not on a robust collection of long-term site-wide site-specific monitoring data showing effectiveness and rates of sulfate reduction-based biodegradation of the COPCs), it is not clear that the proposed EBR/MNA remedial effort is appropriate.	
Work Plan Comments					
1	-	-	259-268	"*The pre-SEE LNAPL Extent Interpretation Update assumes only residual LNAPL at ST012. Between the start of SEE operations and 13 November 2015, greater than 3,500 gallons of mobile LNAPL were removed by bailing and/or pumping from three perimeter monitoring wells (further discussed in Section 2.2.3). The presence of mobile LNAPL during the PDI and the volumes removed during SEE operations indicate that there is mobile LNAPL at ST012; however, it is expected that mobile LNAPL at ST012 is limited in extent compared to residual LNAPL and will be removed via mechanical extraction from wells during both the remainder of SEE operations and EBR system implementation. Because of this, the pre-SEE extent based on residual LNAPL described in this section is used to develop the EBR*	LNAPL monitoring conducted historically and throughout SEE operations provides a robust data set supporting limited extent of mobile LNAPL. LNAPL monitoring and removal since 2011 is documented in ST012 annual groundwater monitoring reports. LNAPL monitoring and removal from perimeter wells during and after SEE is documented in weekly and quarterly operations reports. During SEE, mobile LNAPL was observed in three perimeter wells (W11, W30, W37) where mobile LNAPL was historically present prior to SEE. The weekly and quarterly operations reports have reported that historic and site operations data indicate mobile LNAPL recovered from perimeter wells during SEE operations was due to a hydraulic pressure response associated with the groundwater extraction system. LNAPL recovery peaked in the June to August 2015 timeframe and declined rapidly to no mobile LNAPL recovery when the groundwater extraction system was shutdown. Additionally, most of the 3,500

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				system design, including required TEA mass calculations." *"Assumes only residual LNAPL", "it is expected that mobile LNAPL at ST012 is limited in extent".* While the Site documents present various arguments for these assumptions, it is not clear that there are robust data providing a strong scientific basis for these assumptions and expectations. Therefore, basing the EBR system design on them is problematic. It may be worth noting that if it is feasible to remove much mobile LNAPL by mechanical extraction *("mobile LNAPL at ST012 … will be removed via mechanical extraction from wells")* from wells, it's not clear why this has not been done already. There was some discussion of this possible mechanical extraction effort in the *APPENDIX I Response to EPA Review Comments* portion of the Work Plan, but the discussion did little to clarify the value of such an effort.	gallons of mobile LNAPL was recovered at one location, well W-37. Previously reported data from years of LNAPL monitoring and removal prior to and during SEE supports the assumption that mobile LNAPL at ST012 is limited in extent. The purpose of the mass calculations is to provide a framework for a range of potential mass estimates to formulate the initial EBR treatment plan. The available data were used to make reasonable interpretations for the first phase of EBR. During phased implementation, additional data is collected with each step of implementation and subsequently evaluated to optimize subsequent phases. Mechanical removal of mobile LNAPL has been consistently employed at ST012 for several years (including pre-and post-SEE operations) and is an ongoing process that will be continued throughout EBR remedy implementation. Mechanical removal of mobile LNAPL is valuable to reduce mass and potential migration. Contingency planning included in Addendum 2, Section 4.2.5 provides for mobile LNAPL removal from new and existing wells, and delay of EBR injections where sustained recovery of mobile LNAPL is possible.
2	-	-	331-334	*"Monthly perimeter monitoring well groundwater sampling is conducted at the site to monitor COC concentrations throughout SEE operations (well locations shown in Figure*	Plume delineation was already established when the OU-2 RODA 2 groundwater remedy was selected by the AF and EPA with concurrence from ADEQ. Site operational and monitoring data indicate that COC detections in perimeter wells

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				2-4). Table 2-3 presents the most recent round of perimeter groundwater monitoring data, as well as the minimum and maximum concentrations measured at each well since startup." *"Table 2-3 BTEX+N Groundwater Concentrations During SEE Operations"* Perimeter Monitoring Wells ST012-W11, ST012-W30, ST012-W34, ST012-W36, ST012-W37, and ST012-W38 all show high contaminant concentrations (i.e., one or more of the BTEX+N contaminants). Of these, ST012-W11, ST012-W30, and ST012-W37 have measurable LNAPL in the well (Work Plan, Lines 368-371). Given that these wells are perimeter wells, and there is little monitoring outside the perimeter, it is clear that the plume(s) have not been completely delineated. This lack of plume delineation is problematic not only for EBR, but also for MNA, because EPA policy is that in order for MNA to be chosen as part of a site remedy, the plume has to be completely delineated. *"Site characterization should include collecting data to define (in three spatial dimensions over time) the nature and distribution of contaminants of concern and contaminant sources…"* (USEPA 1999, p14)	above the cleanup levels were transient. Current monitoring (April-June 2016) data indicate that there are no downgradient well locations exceeding the MCL for benzene or other COCs. Additional characterization has been (SEE Pre-Design Investigation) and continues to be performed to facilitate and optimize remedy implementation. Phase 1 EBR implementation included 22 new wells located, in part, to facilitate characterization of post-SEE site conditions including areas where there were transient detections of COCs exceeding the cleanup levels. Prior AF responses to regulatory agency comments in regard to perimeter monitoring wells indicated further characterization associated with these areas would be assessed and implemented based on a cumulative evaluation of post-SEE data from wells within the TTZs, perimeter wells, and the new wells (see AF response letter dated 19 May 2016). This iterative approach to EBR implementation is the best way to continue remedial progress towards achieving the cleanup levels and estimated remedial timeframe while concurrently collecting data to facilitate and optimize the remedy. MNA implementation is premature for ST012. Transition to MNA will be based on EBR achieving conditions (residual COC/COPC groundwater concentrations) at ST012 such that contaminants will degrade by natural attenuation to achieve the cleanup levels within the projected remedial timeframe (Addendum 2 Section 6.1).

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				In addition, USEPA policy for MNA is that contaminant sources must be controlled. *"Furthermore, largely due to the uncertainty associated with the potential effectiveness of MNA to meet remediation objectives that are protective of human health and the environment, EPA expects that source control and long-term performance monitoring will be fundamental components of any MNA remedy."* (USEPA 1999, p3) While significant amounts of source material have been removed (e.g., during SEE) it is clear that significant amounts of source material remain (i.e., NAPL in wells, and high COPC concentrations remaining in some locations both within the main part of the Site and outside in the largely-uncharacterized areas around the Site). Therefore MNA is not applicable for the Site due to the lack of contaminant source control. Note also that the EBR Field Test Report indicates that: "As part of the ST012 Remedial Design and Remedial Action Work Plan (RD/RAWP) (AMEC, 2014a) for implementing the OU-2 RODA 2, the selected remedial action includes an initial period of SEE for mass removal of	The transition of EBR to the MNA component is anticipated to occur in 2019 and will be based on operational and monitoring data including plume delineation sufficient for transition to MNA. The primary source control/removal for the ST012 remedy has been provided by SEE. As described in the Focused Feasibility Study (FFS), the SEE portion of the remedial alternative selected as the ST012 remedy was designed to address the majority of highly contaminated media and reduce the trapped LNAPL source. It is not clear why EPA is disregarding the fact that LNAPL mass outside the thermal treatment zones was an acknowledged element of remedial alternative evaluation in the FFS, remedy selection in the RODA 2, and remedial design in the RD/RAWP. The mass of LNAPL present outside the thermal treatment zone, including ST012-W11, ST012-W30, and ST012-W37, was estimated in the RD/RAWP and the associated areas of groundwater contamination are addressed with EBR, consistent with the selected remedy. The EBR phase of the selected remedy is a source control technology to the extent that it will deplete COCs/COPCs such that groundwater cleanup criteria can be met. The blanket statement that EBR is not a source remedy is not consistent with the state of practice as supported by the following points:

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				dissolved contaminants and light non-aqueous phased liquid (LNAPL) within established thermal treatment zones (TTZs), ***followed by EBR to address LNAPL*** *outside of the TTZs as well as dissolved phase contaminants within and outside the TTZs*." (EBR Field Test Report, Lines 148-152; emphasis added) EBR is not a source (e.g., LNAPL) remedy. EBR might have some efficacy for reducing mass flux of contaminants from source materials into groundwater, but the timeframe for actual removal of a significant mass of source material (e.g., removing the many thousands of pounds of source material estimated to remain after SEE, by dissolution into groundwater and then EBR degradation of the dissolved contaminants) would likely be far longer than the less-than twenty years remaining in the RODA-specified remedial timeframe. The problem with proposing EBR to address LNAPL source materials has been mentioned in previous conference calls, but the *APPENDIX I Response to EPA Review Comments* portion of the Work Plan still indicates that "*SEE is the primary removal mechanism for LNAPL but the RD/RAWP identified that EBR would also address LNAPL*".	• Source control by bioremediation has been implemented at many sites. Bioremediation is more extensively documented for chlorinated solvent source areas but has also been applied for petroleum hydrocarbon sites. One study for chlorinated solvent sites shows that bioremediation source control performance is competitive and in some cases better than other source control technologies (McGuire et al, 2006). • Natural Source Zone Depletion (NSZD) is an established process for LNAPL (ITRC, 2009). Dissolution and biological degradation is one of the primary removal pathways for NSZD. Generally, the timescales of NSZD are not consistent with the timescales in the OU2 RODA 2; however, the proposed approach is designed to accelerate the biological process by providing excess sulfate. • Recent developments in NSZD assessment and monitoring consider the use of measuring carbon dioxide (CO_2) flux from above a LNAPL body as a means to quantify its biodegradation rate. Results of CO_2 flux monitoring above LNAPL bodies show that natural biodegradation of LNAPL can be significant; ranging from hundreds to thousands of gallons per acre per year. Under natural conditions, biodegradation

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					of LNAPL is rate limited based on the flux of TEA. • The primary biodegradation pathway is in dissolved phase; however, there is some evidence of direct biological degradation of LNAPL (ITRC, 2009) • Dissolution of COCs from residual LNAPL may be the rate limiting step (depletion to the point that rate of remaining LNAPL dissolution does not generate MCL exceedances). The AF expects that, with the establishment of a robust bacteria population, dissolution will be enhanced by concentration gradients and generation of biosurfactants. • Sulfate reduction has been observed to be effective at bioremediation of LNAPL associated hydrocarbons (Irianni-Renno et al, 2016). This study points out that "...during the preceding century of LNAPL influence, LNAPL-tolerant microbial communities have been established and microorganisms present readily grow in the presence of LNAPL." Not only are microbes able to biodegrade LNAPL hydrocarbons, they are actively adapting to be more efficient. Irianni-Renno's study also observed metal-sulfide precipitates with no suggestion of deleterious effects. • The notion that bioremediation is not effective on LNAPLs is misleading (Yadav and Hassanizadeh, 2010). In order for bioremediation to occur, the hydrocarbons

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					may need to become solubilized in order to be utilized by microorganisms, so the LNAPL is being degraded, but only after the surface materials partition into solution. Biodegradation rates can exceed advective or dispersive flux thereby driving solubility equilibrium. Also, LNAPL represents the presence of a large electron donor source. As Yadav and Hassanizadeh point out, bioremediation is electron acceptor limited. Because of this, the ST012 site is a uniquely good candidate for the potential success of LNAPL bioremediation due to the high background concentration of sulfate. For bioremediation to be successful, all of the LNAPL does not need to be removed, only enough so that the hydrocarbon flux from the LNAPL is less than or equal to the kinetic capacity of the microorganisms. Yadav and Hassanizadeh point out that the three primary factors that determine the success of LNAPL conditions are: 1) Kinetics (which will be addressed by increasing the sulfate concentration); 2) site-specific conditions (which the field test has shown us to be favorable) and 3) temperature (which is also favorable as a result of the recent SEE operation). • LNAPL is a constant hydrocarbon source, creating a concentration gradient on the

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					periphery. Research has shown that chemotactic bacteria will move toward the LNAPL in response to this gradient (Wang et al, 2012).
3	-	-	413-427	*"COC mass remaining at ST012 was estimated using assumed removal percentages for the TTZ and two zones outside of the TTZ. Based on previous SEE experience, treatment within the TTZ was estimated to remove 90% of initial LNAPL mass. Based on observed temperature increases outside of the TTZ (as described in Section 2.2), a zone of treatment (Thermal Influence Zone [TIZ]) was estimated 10 meters outside of the TTZ. Treatment in this zone was not expected to be as effective because temperatures in this zone have been elevated but have not reached steam temperatures as within the TTZ, so removal was estimated at 60%. A third treatment zone (Radius of Influence [ROI] Zone) was estimated 10 meters outside of the TIZ. Treatment was not targeted or expected in the ROI Zone; however, it has been subject to elevated temperatures and influence from the outer extraction wells. Removal in the ROI Zone is estimated at 30%. The LPZ has not been targeted for SEE treatment because of the difficulties related to injecting steam*	See response to comment 2 with respect to EBR for source treatment. Contaminant mass outside the TTZs was an established element of the FFS and RD/RAWP for the OU-2 RODA 2 remedy. The OU-2 RODA 2 selected remedy for ST012 groundwater is FFS Alternative ST012-3: Steam Enhanced Extraction and Enhanced Bioremediation. FFS Section 4.3 clearly identifies source treatment areas used for Alternative ST012-3, stating source areas were "developed to identify source area treatment areas for the upper water bearing zone and the lower saturated zone that would address the majority of highly contaminated media at ST012 while remaining within accessible boundaries within which it would be feasible to implement in-situ technologies." FFS Section 4.3 also states "The portion of the plume beneath South Sossaman Avenue was deemed inaccessible…" The Final 2014 RD/RAWP specifically identifies EBR and natural attenuation to address contamination outside the SEE thermal treatment zones within the remedial timeframe (Section 4.2.2, page 4-6): "The EBR component of the remedy followed by natural attenuation will address the remaining LNAPL outside the SEE TTZs and the dissolved phase plume to the extent that cleanup levels will be achieved within

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				and extracting liquids and vapor from low permeability soils. However, the LPZ has been influenced by thermal conduction from both the UWBZ and the LSZ, so some treatment is to be expected as LNAPL is driven from the liquid to vapor phase. Because of this, treatment of the temperature-affected LPZ adjacent to the TTZ in the UWBZ and LSZ is estimated at 30%." Even based on these (likely optimistic) estimates, significant contaminant mass remains (many thousands of pounds). As mentioned above, EBR is not a source remedy (e.g., for removal of LNAPL), so the remaining source material will continue to supply contaminants to groundwater for many years (likely well beyond a twenty-year timeframe). In addition, the estimate of only 30% of contaminant mass removal from the LPZ indicates that this zone will continue to supply (e.g., through back diffusion from these low permeability materials) significant quantities of contaminants to groundwater, and over a much longer time period than the more permeable materials.	the estimated remedial timeframe of 20 years." RD/RAWP Figures 3-1 and 3-2 clearly show the extent of LNAPL distribution in relation to the SEE TTZs. The estimated LNAPL mass remaining outside the SEE TTZs is to be addressed in accordance with the above statements was clearly established in RD/RAWP Table 3-2. Based on the conservative mass estimates included in RD/RAWP Table 3-2, groundwater modelling presented in RD/RAWP Appendix E concluded that cleanup levels will be achieved in the estimated remedial timeframe (see Appendix E, Table E-4.15). The RD/RAWP Addendum 2 (Section 2.1 and Appendix A) updated pre- and post-SEE mass estimates based on additional information gathered from 63 new wells installed during SEE implementation and the mass removed during SEE, respectively. The updated mass estimates are less than those included in the original RD/RAWP estimates and model so the conclusion that cleanup levels are predicted to be achieved within the remedial timeframe remains appropriate. With respect to the low permeability zone (and other low-permeability intervals), long-term diffusion of COCs is possible, perhaps likely, from these layers; however, what is key is the rate of back diffusion (i.e., the flux of contaminant from these units) relative to the groundwater flow rate and TEA flux through the more permeable lenses. Complete depletion of LNAPL or COCs is not

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					required if the rate of back diffusion is insufficient to generate exceedances of cleanup levels.
4	-	-	619-624	*"The primary advantages of oxygen as a TEA over sulfate are its faster degradation kinetics and a more extensive track record than sulfate for enhancement of petroleum hydrocarbon degradation. However, these advantages were offset by several other factors that led to the selection of sulfate as the primary TEA at ST012 including:* • *sulfate was demonstrated in the RD/RAWP to be capable of achieving goals in the target timeframes…"* The selection of sulfate over oxygen is reasonable, but it is not at all clear that sulfate EBR is "*capable of achieving goals in the target timeframes…*". The "demonstration" appears to be based on modeling efforts based on limited Site data, numerous assumptions, and the EBR Pilot Test, not (as mentioned in an earlier part of this review) on a robust collection of long-term site- wide site-specific monitoring data showing effectiveness and rates of sulfate reduction-based biodegradation of the COPCs. The EBR Pilot Test, as discussed above, added relatively little useful data to back up the modeling assumptions and	As noted in the response to Field Test Comment 8, the EBR Field Test data was not used in the RD/RAWP EBR timeframe estimates. The modeling was based on available site data and representative modeling assumptions. The model demonstrates a theoretical capability to achieve cleanup goals and is supported by multiple lines of evidence. The referenced bullet has been changed to: • "sulfate was demonstrated in the RD/RAWP *based on theoretical modeling* to be capable of achieving goals in the target timeframes…" The RD/RAWP and Addendum 2 present multiple lines of evidence based on historical data, post TEE data, pre-SEE data and post-SEE data, all of which support the presence and effectiveness of sulfate reduction-based biodegradation at the site. The purpose of phased EBR implementation is to provide for remedy optimization based on robust collection of long-term site-wide site-specific monitoring data showing effectiveness and rates of sulfate reduction-based biodegradation of the COCs. The implementation of sulfate-based EBR and the associated operational monitoring will be used to demonstrate the achievement of project goals within the estimated remedial time frame.

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				estimates. Therefore sulfate EBR has not been practically demonstrated to be capable of achieving goals in the target timeframes. Perhaps sulfate EBR has been demonstrated (under an optimistic view of sulfate distribution, COPC degradation rates, mass and distribution of remaining COPC source material/dissolved COPCs on and off-Site, etc.) to be theoretically capable (i.e., under some modeling scenarios) of achieving goals in the target timeframes. However, the practical value of such a theoretical demonstration remains to be seen.	
EBR Monitoring Comments					
1	-	-	-	The EBR plan includes using sulfate injection wells, and groundwater extraction wells, to enhance and control distribution of reagents throughout the contaminated zone. These injection and extraction wells are proposed to be used for monitoring treatment efficacy and rates also. As was discussed in earlier USEPA comments and conference calls, injection wells are not suited for monitoring sulfate reduction and contaminant degradation, generally, though the monitoring data from such wells is useful. Extraction wells may be useful for monitoring sulfate reduction and contaminant degradation. However, there must be additional monitoring wells used for monitoring sulfate reduction and contaminant degradation (i.e., treatment efficacy and	Data from the three types of wells (injection, extraction, and monitoring-only wells) will be evaluated separately, to avoid comingling of data with different biases. The proposed monitoring-only wells presented in the Addendum were included to evaluate treatment efficacy, rates, and geochemistry and are considered adequate for initial Phase 1 EBR implementation. Consideration of additional wells for characterization, monitoring or remediation will be based on evaluation of post-SEE characterization and EBR implementation results.

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				rates). These problems were discussed and addressed to a degree in the *APPENDIX I Response to EPA Review Comments* portion of the Work Plan, but are enlarged upon in this review to emphasize the necessity differentiation of the data derived from the different types of wells. Injection wells generally work effectively to produce a treated zone immediately around the well, and any samples drawn from such well either include the treated water from immediately around the well (e.g., using low flow sampling) or at least draw formation water through a strongly active treatment zone immediately around the well, so such samples are not particularly representative of treatment in the larger aquifer volume. Extraction wells are more suitable for monitoring treatment efficacy and rates, but nevertheless data from such wells can be problematic because the design and purpose of such wells is to (eventually) draw in water from the injection wells (i.e., water from pathways where distribution of the injected reagents has been successful). That is, the extraction wells are supposed to help move water and reagents from the injection wells through the Site to the extraction wells, thereby helping enhance and control reagent distribution. So, as by design the extraction wells tend to capture	

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				water from pathways where reagent distribution (and presumably, treatment) has been successful, the data from such wells may be biased toward showing more effective treatment than is actually the case in the larger aquifer. Also, the geochemistry around the extraction wells can be changed due to the continuing withdrawal of relatively large volumes of water (as compared to the small volumes of sample taken from ordinary monitoring wells), possibly biasing the monitoring results from such wells. Therefore, it is important to: • Evaluate data from the three types of wells (injection, extraction, and monitoring-only wells) separately, to avoid comingling of data with different biases. • Provide sufficient monitoring-only wells so that treatment efficacy and rates, geochemistry, etc., can be properly evaluated throughout the Site and outside the Site.	
Data Presentation Comment					
1	-	-	-	Data for each monitoring well should be presented separately in tables and figures, to show changes in contaminants and geochemistry. For purposes of overall screening of results, data for injection wells,	This comment pertains to future interpretation of data collected during EBR implementation and will be incorporated into Section 5.6 as follows:

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				extraction wells, and monitoring wells could be grouped (i.e., the group of injection wells, the group of extraction wells, and whatever groups of monitoring wells [e.g., perimeter, TTZ, etc.] might be appropriate) and presented separately from the individual wells. All such tables and figures providing the monitoring data, and associated discussions, should include materials showing how the data collection, analysis and evaluation, and all modeling and statistical approaches meet USEPA data quality objectives. Uncertainty analyses, including sensitivity analyses, confidence limits on predicted values, etc. should be included. The uncertainty analyses should clearly indicate the variability of Site data, and how that variability influences assessment (i.e., understanding of current Site conditions, including hydrogeology, contamination, geochemistry, and microbiology) and predictions of contamination nature (e.g., changes in the BTEX+N mix), contaminant extent (3D location, including off Site areas) and contaminant degree (concentration/mass, including attenuation rates), future changes in Site conditions (hydrology, geochemistry, microbiology, etc.), and predicted timeframes for meeting remedial goals (USEPA 2009). Given the heterogeneous	"Status and data summaries will be presented as part of the routine Base Realignment and Closure Cleanup Team calls and meetings. Validated data, including laboratory analyses and operational data, will be presented on a quarterly basis with the current quarterly soil vapor extraction progress reports for ST012. *Data will be presented and evaluated for each monitoring well to show changes in contaminants and geochemistry with time. The reports will include materials showing how the data collection, analysis, and evaluation meet data quality objectives of the QAPP.* Discharge monitoring reports will be submitted as required by the sewer discharge permit. Copies of discharge monitoring reports will be included in the quarterly reports. *During the timeframe of one to three years after initial EBR injections commence, statistical or modeling evaluations of EBR progress will be completed. Such evaluations will include uncertainty analyses, including sensitivity analyses and confidence limits on predicted values. The uncertainty analyses will indicate the variability of Site data, and evaluate how that variability influences assessment (i.e., understanding of current Site conditions) and predictions of contamination nature (e.g., changes in the BTEX+N mix), contaminant extent, contaminant concentration/mass, contaminant attenuation rates, changes in Site conditions, and predicted timeframes for meeting remedial goals.*"

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				nature of the Site hydrogeology and contaminant nature and distribution, and the problematic nature of the EBR Pilot Study results, it is important to clearly convey the high uncertainty associated with predictions of remedy (e.g., EBR and MNA) success and timeframes.	The AF agrees it is important to clearly convey, as well as acknowledge, accept, and refine, the uncertainties associated with predictions of remedy success and timeframes. Such uncertainties do not preclude remedy implementation and would be reduced based on operations and monitoring data collected while implementing the EBR remedy.

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RESPONSE TO EPA MEMORANDUM (DR. EVA DAVIS) DATED 8 JUNE 2016
DRAFT FINAL ADDENDUM #2
REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY, SITE ST012
FORMER WILLIAMS AFB, MESA, ARIZONA

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General Comment					
1				I have reviewed the Draft Final Addendum #2 to the Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy for Site ST012 Former Williams Air Force Base in Mesa, Arizona, dated March 15, 2016. While this revised document contains additional design information for the enhanced biological remediation (EBR) portion of the remedy, as requested in my previous comment letter, important comments on the ability of EBR to meet the remedial goals in the desired time frame have not been adequately addressed. This is not the remedy that I believed that EPA was agreeing to at the time the Record of Decision Amendment (RODA) was signed. I believed that steam enhanced extraction would be used to recover light nonaqueous phase liquid (LNAPL) and EBR would be used only for dissolved phase contamination. It is my belief that the Addendum does not put forward an EBR plan that is likely to meet the remedial goals in the desired time frame.	The steam enhanced extraction (SEE)/enhanced bioremediation (EBR) remedy was selected by the AF and the U.S. Environmental Protection Agency (EPA) with concurrence from the Arizona Department of Environmental Quality (ADEQ). The Operable Unit 2 (OU-2) Record of Decision Amendment 2 (RODA 2) selected remedy for ST012 groundwater is Focused Feasibility Study (FFS) Alternative ST012-3: Steam Enhanced Extraction and Enhanced Bioremediation. FFS Section 4.3 clearly identifies source treatment areas used for Alternative ST012-3, stating source areas were “developed to identify source area treatment areas for the UWBZ and LSZ that would address the majority of highly contaminated media at ST012 while remaining within accessible boundaries within which it would be feasible to implement in situ technologies.” FFS Section 4.3 also states “The portion of the plume beneath South Sossaman Avenue was deemed inaccessible…” The Final 2014 Remedial Design and Remedial Action Work Plan (RD/RAWP) specifically identifies EBR and natural attenuation to address contamination outside the SEE thermal treatment zones within the remedial timeframe (Section 4.2.2, page 4-6): “The EBR component of the remedy followed by natural attenuation will address the remaining light non-aqueous phase liquids (LNAPL) outside the SEE thermal treatment zones (TTZs) and the dissolved phase plume to the extent that cleanup levels will be achieved within the estimated

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					remedial timeframe of 20 years." RD/RAWP Figures 3-1 and 3-2 clearly show the extent of LNAPL distribution in relation to the SEE TTZs. The estimated LNAPL mass remaining outside the SEE TTZs to be addressed in accordance with the above statements was clearly established in RD/RAWP Table 3-2. Based on the conservative mass estimates included in RD/RAWP Table 3-2, groundwater modelling presented in RD/RAWP Appendix E concluded cleanup levels will be achieved in the estimated remedial timeframe (see Appendix E, Table E-4.15). The RD/RAWP Addendum 2 (Section 2.1 and Appendix A) updated pre- and post-SEE mass estimates based on additional information gathered from 63 new wells installed during SEE implementation and the mass removed during SEE, respectively. The updated mass estimates are less than those included in the original RD/RAWP estimates and model, so the conclusion that cleanup levels are predicted to be achieved within the remedial timeframe remains appropriate. Results of current post-SEE characterization results are yet to be fully interpreted but LNAPL mass appears to remain consistent with the baseline estimate ranges presented in the RD/RAWP Addendum 2. There are some newly drilled locations with indications of LNAPL outside the previously estimated areas of LNAPL distribution, but the impacted depth intervals within and outside the previous distribution areas are less than originally estimated in the LNAPL calculations. In accordance with the RD/RAWP and Addendum 2, LNAPL extents will continue to

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					be refined throughout remedy implementation and optimization.
2				I would like to re-iterate some of the comments made by Dr. Dan Pope of CSS-Dynamac, an expert in EBR, in his May 17, 2016 memo: "it is not clear that the proposed EBR/MNA remedial effort is appropriate" "EBR is not a source (e.g., LNAPL) remedy . . . the timeframe for actual removal of a significant mass of source material . . . would likely be far longer than the less-than twenty years remaining in the RODA-specified remedial timeframe" 'it is not clear that sulfate EBR is "*capable of achieving goals in the target timeframes*"	See separate response to comments document that addresses EPA's (Dr. Dan Pope's) 17 May 2016 comments. The AF agrees with this recommendation included in Dr. Pope's comments: "it is recommended that within at the most two or three years after implementation of EBR, monitoring and operational data be carefully evaluated to determine if the data (primarily the COPC attenuation data; secondary data such as sulfate utilization are of much less importance for assessment of remedy effectiveness) show that the EBR+ monitored natural attenuation (MNA) approach appears likely to be able to meet Site goals within the remaining portion of the fixed remedial timeframe." Concurrent with the implementation of EBR, monitoring and operational data will be evaluated on a regular basis to determine if the EBR+MNA approach will meet objectives and whether additional EBR or contingency actions are needed. Statistical and modeling evaluations of EBR progress will be conducted during the one-to-three-year period after initial EBR injections commence. Inputs and assumptions used for the natural attenuation model included in RD/RAWP Appendix E will be updated to enhance predictions of achieving the estimated remedial

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					timeframe. This will allow for remedy effectiveness to be evaluated based on comparison of operational data to the initial baseline and EBR data.
EBR Field Test Comments					
1	-	-	-	In fact, EBR, as proposed, has substantial probability of making the groundwater at Site ST012 worse than the current conditions, in three ways: 1) Response to EPA comment #16 states, "Sulfate is expected to be consumed by bacteria; however, it is likely that concentrations may exist downgradient that exceed the secondary MCL." Currently the groundwater at the site meets the secondary MCL for sulfate, so this would be a degradation of the downgradient groundwater quality. 2) Response to EPA comment #15, and on page 5-7, states that buildup of hydrogen sulfide, a toxic gas, is possible, and that vapor monitoring will be performed at monitoring wells and vapor purging protocols will be developed for well casings. Many of the new injection wells being installed for EBR are in areas accessible to the public. Figure 4-1 of the Addendum show a concrete vault lid on these wells with a screw cap on the well itself. It appears that the public could gain access to these wells, and thus potentially could be exposed to hydrogen sulfide in these wells due to the injection of extremely large amounts of sulfate. 3) Page 3-8 states that sodium sulfate contains up to 3 mg/kg of arsenic as an impurity. At the planned sulfate injection	1) Sulfate has a secondary maximum contaminant level (MCL) of 250 mg/L that will be exceeded within active EBR treatment areas and may be exceeded downgradient of active treatment areas. As a secondary MCL, this limit is primarily for aesthetic (e.g., taste) considerations rather than for the protection of public health. The increased sulfate would come with the benefit of contaminant reductions, which will reduce potential human health risks. Some background (upgradient) samples contain sulfate concentrations above the secondary MCL, suggesting that, due to existing site conditions, the aquifer is already not ideal for drinking water from an aesthetic perspective. 2) Figure 4-1 has been updated to incorporate the use of a lockable well cap. In Section 4.1.1, text was changed: "If necessary, tubing, and a relocatable injection stinger and wellhead cap, will be developed for use at remote injection locations. *Wellhead cap will be lockable to limit potential exposure to hydrogen sulfide by the public in areas that are not within the secured site limits.* " 3) The arsenic MCL is 10 µg/L and was used as a conservative value for evaluation of

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				concentration of 320 gm/L, the injection water would contain up to 0.96 mg/L of arsenic, which is almost 100 times the drinking water standard for arsenic. It is not clear that injection of this concentration of arsenic is allowed by Arizona state law. Based on the amount of sodium sulfate to be used in Phase I, Amec calculated that the concentration of arsenic in the groundwater would be between 8 and 26 µg/l (see Appendix G). Due to the likelihood of needing considerably more sulfate than proposed for Phase I due to the large mass of contaminant remaining at the site, it is likely that higher arsenic groundwater concentrations will be produced. Amec goes on to claim that "The calculation is conservative and does not take into account any of the following expected mechanisms that would be anticipated to decrease arsenic concentrations upon injection: 1. in situ geochemical conditions that would likely lead to precipitation or adsorption, 2. Consumption of arsenic through biotic and abiotic reactions." However, Ford et al. (Ford, R. G., R. T. Wilkin, & R. W. Puls, Monitored Natural Attenuation of Inorganic Contaminants in Ground Water Volume 2, EPA/600/R-07/140, October 2007) state that reducing chemical environments will cause desorption and dissolution of arsenic. Ford et al. also discuss how arsenic transport via mobile colloids can be enhanced in aquifers impacted by organic contaminants where microbial activity is stimulated resulting in the generation of reducing conditions and/or the	potential groundwater impacts during EBR implementation. The actual Arizona Aquifer Water Quality Standard for arsenic is 50 µg/L, which is less stringent than the MCL. The selected sodium sulfate product data sheet indicates a concentration range of 1 to 3 mg/kg. Calculations discussed in this comment use the conservative value of 3 mg/kg. Quality control data provided by the supplier of the product for the period between 31 March and 3 August 2015 indicates a maximum concentration of 1.4 mg/kg and an average of 0.95 mg/kg. Depending on the actual measured concentration of arsenic in the sodium sulfate product, the full-strength injection solution may fall below the Arizona Aquifer Water Quality Standard. If not, and if injection above this concentration will not be allowed by ADEQ, higher volumes of lower concentration solutions will be used. Although removal of dissolved arsenic in reducing environments can occur, such as in permeable reactive barrier walls, the geochemistry of arsenic is complex and it is agreed that the remedy should not rely on geochemical mechanisms for its removal. Therefore, the calculations presented do not assume any removal of dissolved arsenic in the formation, and use the drinking water MCL as the more conservative criteria. Nevertheless, it is possible that concentrations lower than those predicted by the calculations may occur, due to the unaccounted for geochemical mechanisms referenced above. The end of Section 3.3 was modified as follows:

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				production of low molecular weight compounds. Thus, it should be assumed that under the conditions present at this site, the arsenic will remain in the dissolved phase, and may have enhanced mobility via mobile colloids.	"A calculation was performed to assess the potential impact of injected arsenic on the aquifer, resulting in an estimated arsenic concentration of between 8 and 26 µg/L after EBR operations (Appendix G). The EPA maximum contaminant level for arsenic is 10 µg/L and the Arizona aquifer water quality standard is 50 µg/L (ADEQ, 2009). The calculation does not take into account any of the following mechanisms that *may* decrease arsenic concentrations upon injection: 1. in situ geochemical conditions that would likely lead to precipitation or adsorption, 2. groundwater recharge that will lead to a reduction in dissolved arsenic concentrations, or 3. consumption of arsenic through biotic and abiotic reactions. Monitoring of arsenic concentrations will be performed during implementation. *If required by ADEQ, injection solution concentrations will be reduced depending on the measured concentration of arsenic in the sodium sulfate product to limit the arsenic concentration below 50 µg/L. If this is done, the injection volumes would be proportionately increased.* Any increases of arsenic *groundwater concentrations* during EBR implementation will be monitored after implementation to confirm arsenic levels are returning to background conditions. Details of this monitoring procedure are discussed in Section 5.0."
2	-	-		Despite the concerns that EPA has expressed about apply [sic] this remedy to	Please refer to the response to general comment 1 where the basis of remedy selection, including

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				the large quantity of remaining LNAPL, Amec has proceeded with installing wells to initiate EBR. Several of the installed wells have already shown that LNAPL exists outside of the modeled area believed to contain LNAPL. Slide 22 from the May 19, 2016 conference call shows that LNAPL was encountered at 215 feet below ground surface (bgs) at boring LSZ47, which is approximately 60 feet south of where Amec believed LNAPL to exist in the lower saturated zone (LSZ) (see Figures 2-6, B-6 and B-7). Also, the LNAPL found in boring UWBZ33 at 175 and 190 feet bgs is right at the edge of the modeled LNAPL extent for these depth ranges (see Figures 2-2 and B3), indicating that LNAPL extends beyond the modeled extent. The LNAPL detected in boring LSZ50, as described by Steve Willis (memo of May 18, 2016), indicates that the conservative estimate of LNAPL extent is more appropriate for the 210 to 230 foot depth range. Strong odors at 200 to 212 feet bgs and a positive dye test in boring LSZ46 (Steve Willis memo of June 6, 2016) indicate that LNAPL extends approximately 100 feet further to the south in this area then conservatively modeled in Figure B-6. Thus, it is likely that current estimates of remaining LNAPL are not conservative, but are low. This would indicate that the planned sulfate injections, which are based on minimum mass estimates, are low. This recent data re-inforces the importance of understanding where the LNAPL is and how much there is before making decisions on the appropriate remedial technology to use and determining	the known presence of LNAPL outside the source treatment areas was established in the FFS and carried through the RODA 2 and RD/RAWP stages. The remedy was selected by the AF and EPA based on a mutual understanding of contaminant distribution and enhancement of that understanding is a positive factor allowing for remedy optimization. The updated mass estimates included in Addendum 2 are less than those included in the original RD/RAWP estimates and model so the RD/RAWP conclusion that cleanup levels are predicted to be achieved within the remedial timeframe remains appropriate. While the AF acknowledges SEE termination was based on qualitative, as well as quantitative criteria, the actions taken were consistent with the RODA 2 and RD/RAWP. Current site conditions remain consistent with achieving cleanup levels within the estimated remedial timeframe. Contingency actions are identified based on phased EBR remedy evaluation and optimization. While continued refinement of the extent of LNAPL is ongoing and may affect the extent of the remedy, it does not fundamentally change the remedy selected. Phase 1 EBR borings such as UWBZ32/LSZ47 and UWBZ33/LSZ48 were placed, in part, to address regulatory agency comments and concerns regarding characterizing post-SEE site conditions and contaminant distribution. The LNAPL observations from the Phase 1 locations indicate potential areas that may require treatment, consistent with the EBR remedy optimization objective. As planned, additional groundwater data from these newly installed EBR locations are being collected prior to evaluating

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				the implementation strategy. Complete delineation of the LNAPL and dissolved phase plume should be the first step in determining the appropriate remedial strategy for the remaining LNAPL.	potential adjustments to the EBR approach. The AF has remained committed to achieving the cleanup levels within the estimated remedial timeframe and believes that continued remediation based on phased implementation, data collection, and optimization is the best way to advance the site towards cleanup. Complete delineation of the LNAPL and dissolved phase plume prior to any further remediation delays environmental cleanup at the site reduces the AF's ability to meet the estimated remedial timeframe, and reduces or eliminates the remedial benefits of implementing EBR under post-SEE conditions when the dissolved contamination is most readily available for biodegradation.
3	-	-		In response to previous EPA comments, some contingency planning has been incorporated into the Addendum. However, there are no clear protocols or criteria for determining when the contingencies identified will be implemented. The Addendum only states that contingencies 'will be considered". This does not provide EPA with assurance that differing field conditions will be responded to in the appropriate manner – or responded to at all. I do not consider this to be adequate contingency planning.	In response letters dated 29 March 2016 and 19 May 2016, the AF reiterated its commitment to achieving OU-2 RODA 2 remedial objectives and to collect information in an iterative fashion to evaluate remedy effectiveness. Implementation of contingency actions is likely to require additional technical evaluation of a large amount of real-time operational and monitoring data before final recommendations are made. As described in Addendum 2, "detailed responses will depend on the specific data collected and will be discussed with the EPA and Arizona Department of Environmental Quality as part of regular meetings." While clearly defined protocols are desirable from a planning perspective, they may not anticipate all the permutations of site conditions and risk setting up required actions that may not be the most appropriate at the time of actual implementation. To reduce ambiguity that contingency actions will be implemented (vs.

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					just considered) the sentence introducing the potential contingency actions under each topic has been modified as follows: "In response to this, *one or more of the following* four courses of action *(or similar variations on these actions)* will be *implemented*."
4	-	-		Section 4.2.5, on page 4-11, #4, states, "If mobile LNAPL is observed in a new or existing injection well, the LNAPL will be removed to the extent practical prior to injections. If sustained recovery of LNAPL is possible, TEA injection at that location will be delayed." This is an admission by Amec that EBR is not an appropriate remedial technology for areas with mobile LNAPL. Well W-37 has been continually producing LNAPL since 2013, and approximately ten gallons were recovered as recently as April 29, 2016. Well W-11 has had a fairly stable amount of LNAPL in it for at least the month of April. Both of these wells are currently slated to be injection wells, however, by this contingency criteria, it is not appropriate to use them for that purpose. Thus, there is currently no remediation being contemplated for these two highly contaminated areas beyond occasional removal of LNAPL from the wellbore.	LNAPL in significant quantities was known by the AF and regulatory agencies to exist outside the TTZs throughout remedy selection and planning. It is entirely appropriate and consistent with the remedy to consider and account for the presence of mobile LNAPL during EBR remedy implementation. Continued removal of LNAPL from wells prior to injections recognizes it is more efficient to physically remove mobile LNAPL than to degrade its contaminant of concern components in situ. Removal of mobile LNAPL is a defined element of the OU-2 RODA 2 remedy and will continue to be implemented as an efficient remedy component. The W11 and W37 locations have historically had mobile LNAPL and have always been outside the SEE TTZ where the known presence of LNAPL was established before remedy selection. The removal of mobile LNAPL is not a condemnation of EBR, but is appropriate and more efficient prior to EBR implementation. Significant accumulation of LNAPL in W11 ceased after steam injections were stopped in early March. Accumulation of LNAPL in W37 decreased during the post-steam extraction period and ceased after post-SEE extraction was stopped at the end of April. LNAPL monitoring and removal, when present, continues at

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					perimeter wells and is reported to the regulatory team weekly. The conclusion that there is no remediation contemplated in the W11 and W37 areas is not correct; instead, remediation in these areas is proceeding in a manner consistent with the remedy as defined in the FFS, RODA 2 and RD/RAWP. Planning and implementation of EBR in the W11 and W37 areas will be further optimized via data collection from post-SEE monitoring and Phase 1 EBR implementation.
5	-	-		It appears that dispersion is to be relied on to distribute sulfate throughout the area to be treated, as groundwater flow lines for the injected sulfate solution shown in Figures E-1, E-8, and E-15 do not cover most of the areas on known LNAPL contamination.. The series of model results presented in Figure E-2 to E-7, E-9 to E-14, and E-16 to E-21 show the sulfate distribution (above background concentrations) for each of the vertical treatment zones, and appears to show that the sulfate is expected to move almost the same distance laterally via dispersion as toward the extraction wells while the extraction wells are being pumped. This does not seem reasonable or believable. Considering the significant uncertainty in the pilot test results, as documented by Dr. Pope in his May 17, 2016 memo, it is likely that dispersivity values determined from the same test are also highly uncertain. These figures do not provide confidence that the sulfate can be adequately distributed with the planned injection system.	The model simulates two primary steps in the addition and distribution of sulfate. In step 1, extraction pumping is simulated to pull injected sulfate into place. Step 1 pumping is stopped at the approximate time that the sulfate reaches the extraction well and at that time step 2 begins. Step 2 relies on ambient flow, molecular diffusion, and dispersion to further distribute sulfate. Therefore, the particle tracking shows step 1, the advective flow lines between extraction and injection wells under imposed gradient. Once the pumping stops, the simulation shows the expected movement and redistribution of sulfate under the ambient flow regime, or step 2. The dispersivity constants that were used in the model were 20 feet in the longitudinal direction and 6.7 feet in the transverse direction. The transverse dispersivity constant is the most sensitive to lateral spreading of the sulfate, especially under ambient flow (step 2). The transverse dispersivity value was determined by analyzing the push-pull test: this analysis is included in RD/RAWP Addendum 2 (Appendix C). Considering published values for dispersivity in similar aquifers and at similar scales, the value of 6.7 feet is below the average at approximately

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					9.5 feet (Gelhar, 1992). Based on this rationale, once distributed as part of step 1, the sulfate will advect, diffuse, and disperse as simulated. As described, the analysis is based on the data collected from the site. A phased approach to EBR is proposed, in part, to allow for adjustments to be made in response to remediation system behaviors that differ from modeled approaches. Phase 1 field application will provide further confidence in the approach or indicate changes are needed to improve sulfate distribution.

References

Gelhar, Lynn W., Claire Welty, Kenneth Rehfeldt, 1992. A Critical Review of Data on Field-Scale Dispersion in Aquifers, Water Research, 28-7, pp. 1955-1974.

RESPONSE TO EPA COMMENTS DATED 17 JUNE 2016
DRAFT FINAL ADDENDUM #2
REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY, SITE ST012
FORMER WILLIAMS AFB, MESA, ARIZONA

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General Comment					
1				The 2013 Record of Decision Amendment for this site selected Steam Enhanced Extraction to remove as much of the jet fuel free product as possible from the site and follow on with Enhanced Bioremediation to degrade residual contaminants over time to meet the remedial action objective of reducing benzene concentrations to below MCLs within a twenty year time frame. As indicated in our previous comments, Enhanced Bioremediation is not considered an appropriate source control remedy for Non Aqueous Liquids (NAPL) and EPA did not anticipate that it would be used in this manner when the 2013 RODA was signed. As indicated in our previous letters of March 7, 2016 and May 3, 2016, the Steam Enhanced Extraction System was terminated early, while thousands of pounds of hydrocarbons were still being removed on a daily basis. The current reconnaissance efforts now in progress indicate that a significant amount of fuel NAPL remains at the site, which may exceed even the conservative estimates cited in the Addendum#2 RD/RA Workplan.	The U.S. Environmental Protection Agency (EPA) statement regarding the basis for selecting Steam Enhanced Extraction (SEE) is inaccurate. The 2013 Operable Unit 2 (OU-2) Record of Decision Amendment (RODA 2) did not specify a standard of SEE to, “remove as much of the jet fuel as possible.” Instead, it states that the remedy would transition to enhanced bioremediation (EBR) when the effectiveness of contaminant mass removal by SEE has diminished (RODA 2 Section 1.4, Description of the Selected Remedy). EPA Specific Comment 1 on the Draft RODA 2 indicated the Section 1.4 language was adequate. The RODA 2 selects Focused Feasibility Study (FFS) Alternative ST012-3. The first sentence of the FFS description of Alternative ST012-3 (FFS Section 5.3) is: “Alternative ST012-3 is a combination of technologies designed to address the contamination in groundwater and deep soil gas, while reducing the trapped light non-aqueous phase liquid (LNAPL) source.” The AF agrees removal of LNAPL is advantageous to achieving the remedial objectives but reducing the LNAPL source is not equivalent to removing as much as possible. EPA’s statements regarding unanticipated use of EBR are confusing given EPA’s participation in

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					the previously approved primary documents supporting selection and implementation of the remedy. The SEE/EBR remedy was selected by the AF and EPA with concurrence from the Arizona Department of Environmental Quality (ADEQ). The OU-2 RODA 2 selected remedy for ST012 groundwater is FFS Alternative ST012-3: Steam Enhanced Extraction and Enhanced Bioremediation. FFS Section 4.3 clearly identifies source treatment areas used for Alternative ST012-3, stating source areas were “developed to identify source area treatment areas for the upper water bearing zone (UWBZ) and lower saturated zone (LSZ) that would address the majority of highly contaminated media at ST012 while remaining within accessible boundaries within which it would be feasible to implement in-situ technologies.” FFS Section 4.3 also states “The portion of the plume beneath South Sossaman Avenue was deemed inaccessible…” The Final 2014 Remedial Design/Remedial Action Work Plan (RD/RAWP) specifically identifies EBR and natural attenuation to address contamination outside the SEE thermal treatment zones within the remedial timeframe (Section 4.2.2, page 4-6): “The EBR component of the remedy followed by natural attenuation will address the remaining LNAPL outside the SEE thermal treatment zones (TTZs) and the dissolved phase plume to the extent that cleanup levels will be achieved within the estimated remedial timeframe of 20 years.” RD/RAWP Figures 3-1 and 3-2 clearly show the extent of

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					LNAPL distribution in relation to the SEE TTZs. The estimated LNAPL mass remaining outside the SEE TTZs to be addressed in accordance with the above statements was clearly established in RD/RA WP Table 3-2. Based on the conservative mass estimates included in RD/RAWP Table 3-2, groundwater modelling presented in RD/RAWP Appendix E concluded cleanup levels will be achieved in the estimated remedial timeframe (see Appendix E, Table E-4.15). The RD/RAWP Addendum 2 (Section 2.1 and Appendix A) updated pre- and post-SEE mass estimates based on additional information gathered from 63 new wells installed during SEE implementation and the mass removed during SEE, respectively. The updated mass estimates are less than those included in the original RD/RAWP estimates and model so the conclusion that cleanup levels are predicted to be achieved within the remedial timeframe remains appropriate. SEE was terminated based on analysis of the transition criteria provided in the RD/RAWP. The primary source of mass removal at the end of SEE was from outside the TTZ. Please see the more detailed evaluation of achieving the transition criteria presented in the AF's letter dated March 29, 2016, Response to Timing of Shutdown of Steam Enhanced Extraction System, as well as the March 15, 2016 Defense Base Closure and Realignment (BRAC) Cleanup Team meeting slides for ST012. As discussed

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					above, the use of EBR technology to address remaining mass after SEE was a fundamental element of the remedy and updates to the mass estimate remain consistent with the conclusion of achieving cleanup goals within the remedial timeframe. Results of current reconnaissance are yet to be fully interpreted but LNAPL mass appears to remain consistent with the baseline estimates presented in the RD/RAWP Addendum #2. There are some newly drilled locations with indications of LNAPL outside the previously estimated areas of LNAPL distribution, but the impacted depth intervals within and outside the previous distribution areas are less than originally estimated in the LNAPL calculations. In accordance with the RD/RAWP, LNAPL extents will continue to be refined throughout remedy implementation and optimization.
2				The 2013 ROD Amendment selected Steam Enhanced Extraction followed by Enhanced Bioremediation. The intent of the remedy approved by the regulatory agencies was that these treatments would be operated sequentially: Steam Enhanced Extraction treatment to be applied first to remove the bulk of LNAPL; followed by enhanced bioremediation to degrade residual contamination once the bulk of benzene, toluene, ethylbenzene, xylene (BTEX) constituents were depleted. The intent to now use EBR alone to degrade large quantities of	Based on SEE performance, source LNAPL has been reduced, as prescribed by FFS Alternative ST012-3 selected by the RODA 2. SEE was always expected to be the primary technology for LNAPL removal; however, in developing the remedial alternatives during the FFS, it was recognized that LNAPL existed at the perimeter and outside of the SEE TTZs where EBR would be implemented (see discussion and references provided in response to general comment 1, above). Implementation of EBR remains consistent with the remedy and the estimated remaining mass after SEE is consistent with the

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				untreated LNAPL represents a fundamental change to the remedy which has not been approved by the regulatory agencies. The current EBR workplan is now attempting to degrade large areas of LNAPL which have not received any steam treatment, employing a different remedy than selected in the ROD for these remaining areas of contamination: specifically a variation of Alternative 4, Enhanced Bioremediation and Ozonation, as outlined in the Focused Feasibility Study (FFS). As described in the FFS Alternative 4 was not selected due to "significant uncertainty over (remediation) timeframes, and without a pilot test there is uncertainty regarding the overall effectiveness of the remedy" (Page 89, Long Term Effectiveness and Permanence.) Such a change to the remedy, if approved by the agencies, would warrant a new Proposed Plan, Public Comment Period and Amendment to the ROD.	RD/RAWP. EPA's statements and conclusions regarding EBR are not consistent with the remedy and supporting primary documents. While EBR is ultimately focused on reducing dissolved phase concentrations rather than direct remediation of LNAPL, the RODA 2 does not limit EBR to treatment of only dissolved phase contamination. The focus of the remedy is, and has always been, on dissolved phase COCs. To that end, the RODA 2 has cleanup goals for dissolved phase contaminants, not LNAPL. Dissolved-phase plume concentration contours were used as a basis of the conceptual designs for SEE and EBR in the FFS and RODA 2. The Pre-Design Investigations more clearly defined the extent of LNAPL, and, in the RD/RAWP, it was clearly stated that the EBR design would address LNAPL-impacted zones outside of the thermal TTZs (see statements and references provided in response to general comment 1). During review of the RD/RAWP, EPA commented on the potential extent of LNAPL outside the SEE TTZs and suggested consideration be given to expanding the TTZ and EBR treatment zones; however, EPA did not indicate the approach in the RD/RAWP to be a fundamental change to the remedy. The approach described in Addendum 2 is consistent with the remedy described in the FFS, RODA 2, and RD/RAWP and does not represent a fundamental change to the remedy. Because

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					the areas of highest LNAPL impact were treated with SEE and the LNAPL within the TTZs has been reduced, the uncertainty associated with the EBR in Addendum 2 is not comparable to Alternative 4 of the FFS. The phased EBR implementation approach is designed to allow uncertainties to be addressed as the remedy progresses.
Specific Comments					
1	-	-	-	The mass of remaining LNAPL has not been quantified. During the April 21 BCT call, your contractor clarified that the current characterization and reconnaissance effort is not intended to quantify the remaining mass. Without clearly established baseline conditions, How will progress of the remedy be evaluated? How the quantity of amendment will ultimately needed be determined?[sic]	LNAPL extent will continue to be refined throughout remedy implementation phases. Mass estimates will always include a significant degree of uncertainty even with additional delineation and are primarily useful for order of magnitude estimates in remedy planning. The OU-2 RODA 2 acknowledges this uncertainty in Section 3.2.3: "a precise distribution and volume of LNAPL beneath ST012 will never be known". Progress of the remedy will be evaluated based primarily on the RODA 2 cleanup criteria, which are dissolved phase concentrations of COCs. The quantity of amendment ultimately needed will be determined based on feedback from the site (i.e., monitoring data) and adjustments made based on data collected during implementation of EBR.
2	-	-		The proposed sodium sulfate amendment contains arsenic, and the injection solution is likely to exceed 100 times the arsenic MCL. (See Eva Davis memo, attached) It is not clear if this is permissible under state law.	See response to the EPA memorandum by Eva Davis (EBR Field Test Comment 1).

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3	-	-		The sodium sulfate amendment has the potential to significantly increase the salinity of the water, and the Addendum 2 RDRA Workplan has not addressed this.	The EBR injections will increase salinity of the groundwater in the treatment area. The only applicable standard identified relating to salinity is a secondary maximum contaminant level (MCL) for total dissolved solids (TDS) of 500 mg/L. Secondary MCLs are established for nuisance conditions, not for the protection of public health. Fresh water typically has TDS values up to 1,000 mg/L or higher depending on the reference. Background TDS concentrations have not been characterized at ST012. From the groundwater model concentration transport figures showing sulfate for each zone in Appendix E, the injected concentration of sulfate reduces by approximately two orders of magnitude in most areas of the site over a period of about five years and reduces by approximately one order of magnitude in the worst case areas (vicinity of UWBZ injection wells) over five years. Assuming most of the sulfate is converted to sulfide by the EBR process (removing oxygen mass from quantified TDS concentrations), assuming the sulfide does not precipitate (a conservative assumption), and accounting for the sodium component of the injected sodium sulfate solution, the remaining TDS would be about 80% by weight of the sulfate concentrations shown on the figures in Appendix E. Generally, a three orders of magnitude reduction from injected concentrations is necessary to approach the secondary MCL for TDS. Based on this information it is reasonable to project that salinity (as TDS) will be less than 1,000 mg/L and will approach the secondary

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					MCL, depending on background TDS, over the vast majority of the site within the remedial timeframe (20 years post RODA 2). However, it is possible that some localized areas will have higher concentrations (e.g., up to 5,000 mg/L TDS). This discussion will be added to Section 3.3.
4	-	-		The amendment also has the potential to generate hydrogen sulfide gas, which the EBR workplan acknowledges but does not quantify, and does not present a contingency plan to address this public safety concern.	In accordance with the response to EPA specific comment 15 on the Draft Addendum 2, Section 5.4 of the Addendum addresses hydrogen sulfide monitoring and contingency plans for future phases based on hydrogen sulfide measurements: "The health and safety plan will include monitoring of well headspaces for hazardous hydrogen sulfide concentrations and will also include protocols for purging well casings or other precautions to address potential buildup of hydrogen sulfide concentrations. If excessive hydrogen sulfide concentrations are observed in the breathing area (e.g., greater than 5 ppm, based on the recommended short-term exposure limit published by the American Conference of Governmental Industrial Hygienists), adjustments to TEA dosing will be considered for future phases. If concentrations exceed 20 ppm (the Occupational Safety and Health Administration ceiling limit for general industry), action will be taken to protect worker safety." If biological inhibition is observed, inhibition by hydrogen sulfide, among other potential factors,

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					will be evaluated and adjustments made to future injections, if appropriate. In addition, the well detail has been modified to specify that locking caps will be used to limit potential exposure to hydrogen sulfide by the public in areas that are not within the secured site limits. Section 4.1.1 has been changed as described in response to Eva Davis EBR Field Test comment 1.
5	-	-		The phased approach has the potential to create new environmental hazards for the Air Force to address in the future, that were unforeseen at the time of the ROD, and unexpected from a reinterpretation of the remedy which has not been approved by the regulatory agencies.	As discussed in response to general comments 1 and 2, there has been no reinterpretation of the remedy and implementation of the remedy remains consistent with the primary documents. The phased approach included in the RD/RAWP Addendum 2 allows iterative evaluation and optimization that minimizes the potential for environmental hazards.
6	-	-		EPA continues to be very concerned about the potential of the plume spreading, as indicated in or [sic] letter of May 3, 2016. The heated LNAPL is now more mobile and no longer contained and may represent an emergency situation if hot fluids are allowed to spread uncontrolled.	The AF continues to demonstrate site containment through monitoring and additional site characterization. A detailed response to contaminant containment concerns was provided in the AF's 19 May 2016 response letter. Concerns regarding potential spreading of contaminants would be mitigated by EBR remediation, which is being delayed by EPA. The EBR approach in Addendum 2 includes an extraction system in conjunction with providing conditions to promote degradation of contaminants at the downgradient areas of the site which would further ensure plume containment at ST012. The technical and

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					practical premise for uncontrolled spreading of hot fluids is unfounded.
Concluding Statement					
				The potential for spreading of the plume was also acknowledged as a significant concern in the FFS for EBR treatment alone under Alternative 4. Along with untested and uncertain efficacy, risks to the community and long term impacts to adjacent property as were previously identified in the FFS for Alternative 4, as well as the likelihood of creating a costly new environmental problem to address in the future, we believe the current proposal should be reevaluated and reconsidered, and emergency action should be taken to resume extraction for hydraulic containment.	EPA appears to be revising the remedy interpretation based on dissatisfaction with termination of SEE. The potential for plume spreading has been reduced by removal of nearly 500,000 gallons of fuel contamination and would be further mitigated by implementation of EBR. While the AF acknowledges that SEE termination was based on qualitative, as well as quantitative criteria, the actions taken were consistent with the RODA 2 and RD/RAWP. Current site conditions remain consistent with achieving cleanup levels within the estimated remedial timeframe. Contingency actions are identified based on phased remedy evaluation and optimization. Alternative 4 of the FFS consisted of air sparging for aerobic EBR with the addition of ozone. The risk of plume spreading identified for this alternative was primarily associated with the implementation of sparging without active hydraulic control and represents a completely different implementation approach than the injection/extraction approach described in Addendum 2. Based on the different technologies and methods of implementation, application of Alternative 4 evaluations to the EBR proposed in Addendum 2 are inaccurate and inappropriate.

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